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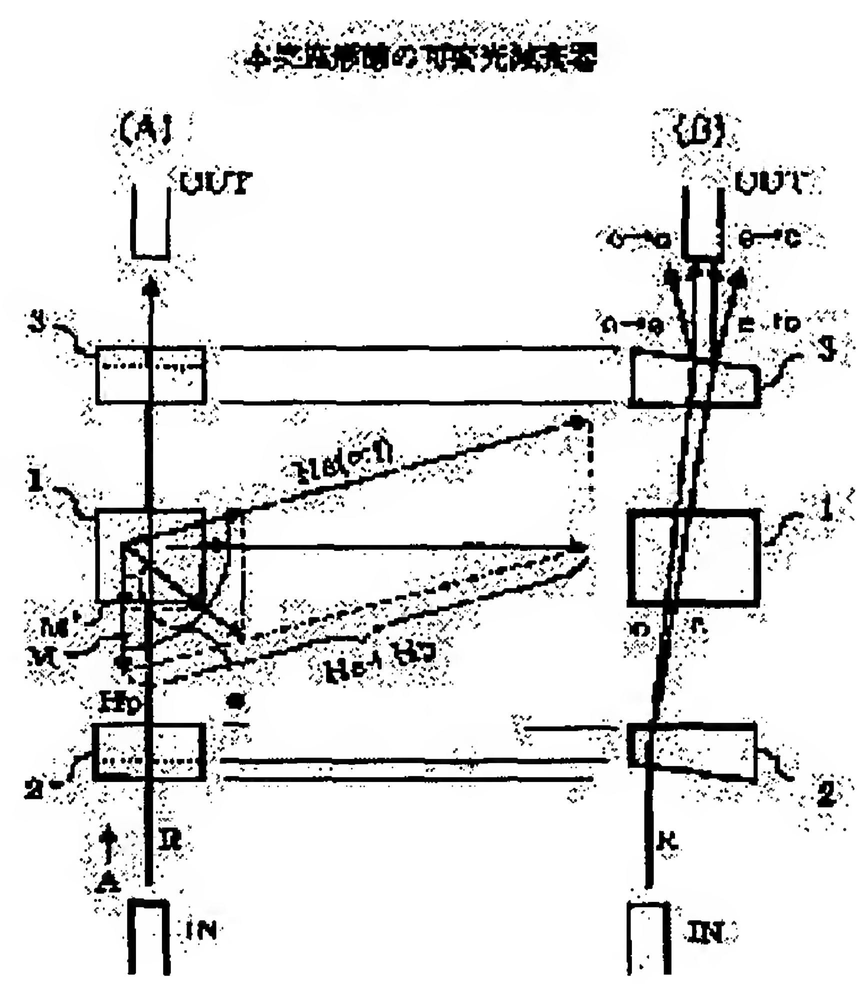
(54) VARIABLE OPTICAL ATTENUATOR UTILIZING FARADAY EFFECT

(57)Abstract:
PROBLEM TO BE SOLVED: To provide a variable optical attenuator, which reduces the dependence over the entire part of the device upon wavelengths through optimization of a magnetic optical system by taking the dependence of a Faraday rotation angle upon wavelengths into consideration.
SOLUTION: The variable optical attenuator has a Faraday rotor 1 which imparts variable Faraday rotation angles and a polarizer 2 and analyzer 3, arranged in front of and behind the Faraday rotor 1. The angle formed by the optical axis of the analyzer 3 with respect to the optical axis of the polarizer 2 is set, in such a manner that the Faraday rotation angle, when the dependence of an optical attenuation quantity on the wavelengths is maximized attains approximate 0, by which the dependence of the optical attenuation quantity on the wavelengths at the Faraday rotation angle is lessened.



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CLAIMS

[Claim(s)]
[Claim 1] With the Faraday-rotation child who gives an adjustable Faraday-rotation angle to the polarization to penetrate The element which starts the linearly polarized light arranged on the ray axis before and behind this Faraday-rotation child, respectively, So that it may be the good light variation attenuator from which the optical magnitude of attenuation changes with change of ****** and the aforementioned Faraday-rotation angle and a Faraday-rotation angle in case the wavelength dependency of the optical magnitude of attenuation becomes the maximum may become 0 degree of abbreviation The good light variation attenuator using the Faraday effect characterized by setting up the angle which the optical axis of the element of another side to the optical axis of one element of the elements which start the aforementioned linearly polarized light makes.
[Claim 2] It has a magnetic field generating means to give the aforementioned Faraday-rotation child the fixed magnetic field and adjustable magnetic field where it is a good light variation attenuator according to claim 1, and directions differ mutually. By setting up each direction of the aforementioned fixed magnetic field and the aforementioned adjustable magnetic field so that the state where the direction of the synthetic magnetic field formed in the aforementioned fixed magnetic field and the aforementioned adjustable magnetic field intersects perpendicularly in the direction of a beam of light may be included The good light variation attenuator using the Faraday effect characterized by enabling a setup of a Faraday-rotation angle at 0 degree.
[Claim 3] The good light variation attenuator which is a good light variation attenuator according to claim 2, and used the Faraday effect to which the direction of the aforementioned adjustable magnetic field is characterized by making an obtuse angle to the direction of the aforementioned fixed magnetic field when the direction of the aforementioned fixed magnetic field is parallel to the direction of a beam of light.
[Claim 4] The good light variation attenuator which is a good light variation attenuator according to claim 2, and used the Faraday effect to which the direction of the aforementioned adjustable magnetic field is characterized by making an obtuse angle to the direction component of a beam of light of the aforementioned fixed magnetic field when the direction of the aforementioned fixed magnetic field is not parallel to the direction of a beam of light.
[Claim 5] With two polarizing elements which start polarization, and the Faraday-rotation child who prepared between these polarizing elements The 1st magnet which adds a magnetic field in parallel with the same shaft as the shaft of the light which passes this Faraday-rotation child, It is the good light variation attenuator which formed the 2nd magnet arranged so that the direction of a magnetic field may serve as an obtuse angle to the direction of the magnetic field of this 1st magnet, and used the Faraday effect by which it is adjusting [this 2nd magnet]-magnetic field strength characterized.
[Claim 6] The good light variation attenuator which is a good light variation attenuator according to claim 5, and used the Faraday effect characterized by enabling it to take the position where the direction of the synthetic magnetic field of the magnetic field of the 1st magnet of the above and the magnetic field of the 2nd magnet of the above becomes perpendicular to the shaft of the aforementioned light by adjusting the magnetic field strength of the 2nd magnet of the above.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] this invention relates to the lightwave transmission system using the good light variation attenuator and it which reduced the wavelength dependency of an optical property especially about the optical attenuator which obtains an adjustable optical property using the Faraday effect.
[0002]
[Description of the Prior Art] The good light variation attenuator using the Faraday effect which is one of the magneto-optical effects is widely used as components, such as a lightwave transmission system. For example, in the system which has a light amplifier, the good light variation attenuator using the Faraday effect etc. is used in order to maintain the output level of a light amplifier uniformly. When such a good light variation attenuator generally changes the force current to an electromagnet etc., a bird clapper is one feature at the composition which a Faraday-rotation child's angle of rotation changes, and the optical magnitude of attenuation is not decided according to a setup of this angle of rotation, and does not have a mechanical movable portion.
[0003] As concrete composition of the good light variation attenuator using the conventional Faraday effect, there are some which were indicated by JP,61-35428,A, JP,6-51255,A, etc., for example.
[0004]
[Problem(s) to be Solved by the Invention] By the way, the Faraday-rotation child applied to the above conventional good light variation attenuators has the wavelength dependency according to the Faraday-rotation angle in physical properties. Moreover, it is also known for the composition which carries out adjustable control of the Faraday-rotation angle by the synthetic magnetic field formed like the conventional good light variation attenuator indicated by JP,6-51255,A in the fixed magnetic field and adjustable magnetic field which intersect perpendicularly that a certain amount of [magnitude of attenuation / optical / the] wavelength dependency will arise. For this reason, in the conventional good light variation attenuator, the level of output light will come to change according to wavelength with each wavelength dependencies of a Faraday-rotation angle and an optical damping property. If the wavelength multiplex (WDM) lightwave transmission system etc. was built using such a conventional good light variation attenuator, since it becomes the cause of optical level being different for every wavelength channel, and inducing the nonlinear effect on a transmission line, it is not desirable.
[0005] this invention was made paying attention to the above-mentioned point, and optimizes a magneto-optics system in consideration of the wavelength dependency of a Faraday-rotation angle, and it aims at offering the lightwave transmission system using the good light variation attenuator and it aiming at reduction of the wavelength dependency in the whole device.
[0006]
[Means for Solving the Problem] In order to attain the above-mentioned purpose, one mode of the good light variation attenuator using the Faraday effect by this invention With the Faraday-rotation child who gives an adjustable Faraday-rotation angle to the polarization to penetrate The element which starts the linearly polarized light arranged on the ray axis before and behind this Faraday-rotation child, respectively, So that it may be the good light variation attenuator from which the optical magnitude of attenuation changes with change of ****** and a Faraday-rotation angle and a Faraday-rotation angle in case the wavelength dependency of the optical magnitude of attenuation becomes the maximum may serve as 0 degree of abbreviation The angle which the optical axis of the element of another side to the optical axis of one element of the elements which start the aforementioned linearly polarized light makes is set up.
[0007] With this composition, the time when a Faraday-rotation angle is smaller takes into consideration the inclination for the wavelength dependency to be reduced, about the optical magnitude of attenuation of a good light variation attenuator paying attention to a Faraday-rotation angle in case the wavelength dependency becomes the maximum. The

angle which the optical axis of the element of another side to the optical axis of one element of the elements which start the linearly polarized light makes is set up so that the Faraday-rotation angle from which the wavelength dependency of the optical magnitude of attenuation becomes the maximum may serve as 0 degree of abbreviation. Thereby, the wavelength dependency of the optical magnitude of attenuation in the Faraday-rotation angle made 0 degree of abbreviation comes to be reduced.
[0008] It is setting up each direction of a fixed magnetic field and an adjustable magnetic field, and it is desirable to enable a setup of a Faraday-rotation angle at 0 degree so that it may have a magnetic field generating means to give a Faraday-rotation child the fixed magnetic field and adjustable magnetic field where directions differ mutually about the above-mentioned good light variation attenuator and the state where the direction of the synthetic magnetic field formed in a fixed magnetic field and an adjustable magnetic field intersects perpendicularly in the direction of a beam of light may be included. Specifically, when the direction of a fixed magnetic field is parallel to the direction of a beam of light, the direction of an adjustable magnetic field should just make an obtuse angle to the direction of a fixed magnetic field. Or when the direction of a fixed magnetic field is not parallel to the direction of a beam of light, you may make it the direction of an adjustable magnetic field make an obtuse angle to the direction component of a beam of light of a fixed magnetic field.
[0009] Since the direction component of a beam of light of magnetization of a Faraday-rotation child serves as zero in the state where the direction of the synthetic magnetic field formed in a fixed magnetic field and an adjustable magnetic field intersects perpendicularly in the direction of a beam of light according to this composition, Faraday-rotation angle =0 degree comes to be realized.
[0010] Other modes of the good light variation attenuator using the Faraday effect by this invention With two polarizing elements which start polarization, and the Faraday-rotation child who prepared between these polarizing elements Forming the 1st magnet which adds a magnetic field in parallel with the same shaft as the shaft of the light which passes this Faraday-rotation child, and the 2nd magnet arranged so that the direction of a magnetic field may serve as an obtuse angle to the direction of the magnetic field of this 1st magnet, this 2nd magnet enables it to adjust magnetic field strength. Moreover, you may enable it to take the position where the direction of the synthetic magnetic field of the magnetic field of the 1st magnet and the magnetic field of the 2nd magnet becomes perpendicular to the shaft of light by adjusting the magnetic field strength of the 2nd magnet about the above-mentioned good light variation attenuator.
[0011]
[Embodiments of the Invention] First, the basic composition and the principle of operation using the Faraday effect of a general good light variation attenuator are explained briefly.
[0012] Drawing 1 is drawing showing the magneto-optics system of a general good light variation attenuator, (A) is a plan and (B) is a side elevation. In addition, the result which performed ray tracing is also shown in drawing 1 (B).
[0013] As shown in drawing 1 , in a general good light variation attenuator, the polarizer 2 which is an element which starts the linearly polarized light, the Faraday-rotation child 1, and the analyzer 3 which starts the linearly polarized light are arranged in order along the direction of a beam of light of the light by which incidence is carried out. Moreover, as shown to the Faraday-rotation child 1 at drawing 1 (A), to the direction of a beam of light, the fixed magnetic field Hp is impressed in parallel, and the adjustable magnetic field helium is impressed perpendicularly. For example, it generates with a permanent magnet which is mentioned later (the 1st magnet), and this fixed magnetic field Hp gives sufficient magnetic field (saturation magnetization is set to M) to saturate a Faraday-rotation child's magnetization. Moreover, for example, it generates with an electromagnet which is mentioned later (the 2nd magnet), and the adjustable magnetic field helium serves as adjustable by changing the force current I to this electromagnet. Therefore, synthetic magnetic field Hp+helium of the fixed magnetic field Hp and the adjustable magnetic field helium changes the size and direction according to the size of force current I.
[0014] Although a Faraday-rotation child's Faraday-rotation angle is decided by the angle of the magnetic field to magnetic field strength and a beam of light, a Faraday-rotation child is that the magnetic field helium perpendicular to a beam of light changes, and the angle to the beam of light of synthetic magnetic field Hp+helium changes since magnetization has reached saturation by the magnetic field Hp parallel to a beam of light, and intensity-of-magnetization M' to the direction component of a beam of light changes. It can carry out adjustable [of the Faraday rotation] by change of intensity-of-magnetization M' to this direction component of a beam of light.
[0015] In the good light variation attenuator which has the above basic composition, as shown in the ray tracing of drawing 1 (B), the beam of light R by which outgoing radiation was carried out is separated into an ordinary ray o and an extraordinary ray e from the input optical fiber IN in polarizers 2 (for example, wedge type rutile etc.) according to the wedge angle. After the separated ordinary ray o and an extraordinary ray e receive Faraday rotation which is proportional to the size of magnetization component M' of the direction of a beam of light in the Faraday-rotation child

1, respectively, incidence of them is carried out to analyzers 3 (for example, wedge type rutile etc.). Here, it is arranged so that the optical axis of an analyzer 3 may become almost parallel to the Faraday-rotation angle when considering force current I as abbreviation 0 (about the detail of an optical axis, it mentions later), and the component (o->o component in drawing) which is equivalent to an ordinary ray among the ordinary rays o in a polarizer 2 with an analyzer 3 comes to combine with the output optical fiber OUT. Moreover, the component (e->e in drawing) which is equivalent to an extraordinary ray among the extraordinary rays e in a polarizer 2 with an analyzer 3 as well as this is combined with the output optical fiber OUT. Furthermore, about the ordinary ray o and extraordinary ray e in a polarizer 2, since a Faraday-rotation angle is adjustable according to the size of the adjustable magnetic field helium, each ratio of an ordinary ray component and an extraordinary-ray component separated with an analyzer 3 can be set as a necessary value. That is, since the above-mentioned ratio changes according to a Faraday-rotation angle, changing the quantity of light combined with the output optical fiber OUT comes to function as a possible next door good light variation attenuator.

[0016] Here, the relation of the optical axis of a polarizer 2 and an analyzer 3 is explained. Drawing 2 is drawing showing the relation of a general optical axis. However, each optical axis shows the case where it sees from the direction shown in the arrow A of drawing 1 (A). Moreover, about the illustrated angle, the optical axis of a polarizer 2 is made into criteria (0 degree), and the direction of counterclockwise is made positive.

[0017] As mentioned above, the input beam of light R is divided into the extraordinary ray e with plane of polarization parallel to the optical axis, and the ordinary ray o with plane of polarization perpendicular to this by penetrating a polarizer 2. By the following explanation, the movement of the polarization about an extraordinary ray e is concretely considered among the separated beams of light. In addition, explanation here is omitted in order for what is necessary to be just to assume the case where 90 degrees of angles are rotated about the below-mentioned contents since it intersects perpendicularly with an extraordinary ray e about an ordinary ray o.

[0018] Although the extraordinary ray e which penetrated the polarizer 2 next penetrates the Faraday-rotation child 1, necessary Faraday rotation according to the size of the adjustable magnetic field helium is received at this time. For example, since it becomes only the fixed magnetic field Hp by the permanent magnet when the force current I to an electromagnet is set as 0 and the adjustable magnetic field helium has hardly occurred, direction component of beam of light M' of magnetization of the Faraday-rotation child 1 becomes equal to saturation magnetization M, and maximum thetamax is obtained as Faraday-rotation angle thetaf. A component parallel to the optical axis of an analyzer 3 turns into an unusual light component in an analyzer 3, and only this component combines with the output optical fiber OUT the beam of light which received Faraday rotation of maximum angle thetamax. Since the joint efficiency to the output optical fiber OUT becomes the best, the loss generated at this time (theta f=theta max, I= 0) turns into an insertion loss as a good light variation attenuator.

[0019] Next, if force current I is changed and the adjustable magnetic field helium is enlarged, in connection with direction component of beam of light M' of magnetization of the Faraday-rotation child 1 decreasing, Faraday-rotation angle thetaf will also become small. In order that the optical-axis component of the analyzer 3 about a beam of light which received Faraday rotation may decrease by this, the joint efficiency to the output optical fiber OUT falls, and it is observed as adjustable optical attenuation. Moreover, since the optical-axis component of the analyzer 3 about a beam of light which received Faraday rotation is set to 0 when the optical axis of an analyzer 3 and Faraday-rotation angle thetaf cross at right angles, the maximum optical magnitude of attenuation comes to be obtained. Faraday-rotation angle thetaf at this time is set to thetaATTmax. Here, if the angle which optical-axis 3a of an analyzer 3 makes to the Faraday-rotation child's 1 hand of cut (drawing 2 the direction of counterclockwise) is set to thetap to optical-axis 2a of a polarizer 2, the relation of p-90 degree of theta ATTmax=theta will be realized.

[0020] If the optical magnitude of attenuation ATT as a good light variation attenuator is formula-ized based on the contents mentioned above, it can express with the relation shown in the following (1) formula.

ATT[dB] =-10 and log10[cos2 (thetap-thetaf)
+ 10(-ER/10)] -- (1)

Here, ER expresses the extinction ratio of the optical crystal used as a Faraday-rotation child 1, and expresses the maximum in good light variation attenuation.

[0021] Next, the cause of generating of the wavelength dependency in the conventional good light variation attenuator which was mentioned above is explained. Drawing 3 is drawing explaining the wavelength dependency of Faraday-rotation angle thetaf.

[0022] In drawing 3 , a horizontal axis shows the wavelength of input light and the vertical axis shows the deflection of the Faraday-rotation angle in the other wavelength when being based on Faraday-rotation angle thetaf with a wavelength of 1549nm as a value showing a wavelength dependency. In the good light variation attenuator mentioned above, when it is made for Faraday-rotation angle thetaf to be set to maximum thetamax when it sets up so that the

optical magnitude of attenuation may be set to about 0dB namely, the deflection of Faraday-rotation angle thetaf in the wavelength range of 1535-1563nm comes to exceed **2 degrees, and it turns out [of a wavelength dependency] that it is large. The wavelength dependency of this Faraday-rotation angle thetaf enlarges the optical magnitude of attenuation with 10dB and 20dB, namely, has the inclination which becomes small in connection with making Faraday-rotation angle thetaf small. Specifically, when the optical magnitude of attenuation is set as 20dB, it turns out that the deflection of Faraday-rotation angle thetaf in the wavelength range of 1535-1563nm becomes smaller than **0.5, and the wavelength dependency is decreasing.

[0023] If the relation between Faraday-rotation angle thetaf in the general good light variation attenuator based on the wavelength dependency of the above Faraday-rotation angles and force current I is computed, it will become a property as shown in drawing 4 . However, a horizontal axis shows force current I, a left vertical axis shows Faraday-rotation angle thetaf, and the vertical axis of the method of the right shows the wavelength dependency deltathetaf (deflection of the Faraday-rotation angle in the other wavelength when being based on Faraday-rotation angle thetaf with a wavelength of 1549nm) of a Faraday-rotation angle. Moreover, angle thetap which a polarizer 2 and an analyzer 3 make assumes the case where it is set as 105 etc. degrees etc.

[0024] As shown in drawing 4 , as for the wavelength dependency deltathetaf of a Faraday-rotation angle, force current I roughly understands a bird clapper for the smaller time. This expresses the property as the relation which Faraday-rotation angle thetaf is because it becomes large, and showed to above-mentioned drawing 3 when small that force current I is the same.

[0025] On the other hand, if the relation of the optical magnitude of attenuation ATT and force current I which were made to correspond to drawing 4 is computed using the above-mentioned (1) formula, it will become a property as shown in drawing 5 . However, a horizontal axis shows force current I, a left vertical axis shows the optical magnitude of attenuation ATT, and the vertical axis of the method of the right shows wavelength dependency deltaATT (deflection of the optical magnitude of attenuation in the other wavelength when being based on the optical magnitude of attenuation ATT with a wavelength of 1549nm) of the optical magnitude of attenuation. Moreover, the maximum (value of ER in the above-mentioned (1) formula) of the optical magnitude of attenuation ATT is calculating by setting it as 25dB here.

[0026] As shown in drawing 5 , when force current I is set as about 50mA, a bird clapper roughly understands wavelength dependency deltaATT of the optical magnitude of attenuation. In this case, specifically, the optical magnitude of attenuation ATT is set to about 21.2dB, and wavelength dependency deltaATT of the optical magnitude of attenuation in the wavelength range of 1535-1563nm becomes large with about 1.1dB. In addition, Faraday-rotation angle thetaf when setting force current I to about 50mA becomes about 19 degrees from drawing 4 . The above causes of generating of wavelength dependency deltaATT of the optical magnitude of attenuation can be explained as follows.

[0027] (1) From the formula, the optical magnitude of attenuation ATT includes the term of log [cos2 (thetap-thetaf)]. The relation between this term and theta p-theta f and its differential coefficient come to be shown in drawing 6 . That is, when large (theta p-theta f is small), the differential coefficient of log [cos2 (thetap-thetaf)] has very small Faraday-rotation angle thetaf. That is, by the wavelength dependency of Faraday rotation, even if thetaf changes, it means that log [cos2 (thetap-thetaf)] is hardly influenced.

[0028] On the other hand, since Faraday-rotation angle thetaf becomes [the differential coefficient of log [cos2 (thetap-thetaf)]] very large when small (theta p-theta f is large) (it starts from the place where the value of theta p-theta f exceeded 85 degrees especially rapidly), log [cos2 (thetap-thetaf)] changes a lot. Therefore, wavelength dependency deltaATT of the optical magnitude of attenuation as shown in above-mentioned drawing 5 comes to be shown. However, near maximum ER of the optical magnitude of attenuation determined by the extinction ratio of optical crystal (it sets to drawing 5 and is near I= 62mA), since the optical magnitude of attenuation ATT is reaching the ceiling, wavelength dependency deltaATT is abbreviation 0 exceptionally.

[0029] An important thing is that wavelength dependency deltaATT of the optical magnitude of attenuation does not necessarily become the maximum at the time of the maximum [dependency / wavelength / deltathetaf / of a Faraday-rotation angle] here, although wavelength dependency deltaATT of the optical magnitude of attenuation is generated in the wavelength dependency of Faraday-rotation child 1 the very thing.

[0030] Then, in this invention, the good light variation attenuator by which the wavelength dependency was reduced by thing [a thing] mentioned above, and which optimize a magneto-optics system about the good light variation attenuator of general basic composition in consideration of each wavelength dependencies deltathetaf and delta ATT of a Faraday-rotation angle and the optical magnitude of attenuation is made realizable.

[0031] In the good light variation attenuator which specifically has a magneto-optics system as shown in drawing 1 and drawing 2 , as drawing 4 and drawing 5 showed, when Faraday-rotation angle thetaf is about 19 degrees, wavelength

dependency deltaATT of the optical magnitude of attenuation serves as the maximum. On the other hand, if Faraday-rotation angle thetaf is small enough so that drawing 3 may show, the wavelength dependency deltathetaf of a Faraday-rotation angle will become small. That is, Faraday-rotation angle thetaf in the state where wavelength dependency deltaATT of the optical magnitude of attenuation serves as the maximum can reduce wavelength dependency deltaATT of the optical magnitude of attenuation by optimizing the relation (angle thetap to make) between optical-axis 2a of a polarizer 2, and optical-axis 3a of an analyzer 3 so that it may move to the small field of the wavelength dependency deltathetaf of a Faraday-rotation angle (that is, Faraday-rotation angle thetaf approaches 0 degree like).
[0032] However, it is impossible by the magneto-optics system as shown at drawing 1 and drawing 2 to make small even at 0 degree of abbreviation the Faraday-rotation angle thetadeltaATTmax from which wavelength dependency deltaATT of the optical magnitude of attenuation becomes the maximum. Because, although the size of the adjustable magnetic field helium must be made infinite in order for the fixed magnetic field Hp and the adjustable magnetic field helium to lie at right angles mutually and to make Faraday-rotation angle thetaf 0 degree of abbreviation in general basic composition, as shown in drawing 1 , since the size of the adjustable magnetic field Hp is limited, it is based on a difficult thing. Therefore, by this invention, further reduction of wavelength dependency deltaATT of the optical magnitude of attenuation is aimed at by optimizing each direction of the fixed magnetic field Hp to the direction of a beam of light, and the adjustable magnetic field helium.
[0033] Hereafter, the operation gestalt of the good light variation attenuator by this invention is explained based on a drawing. Drawing 7 is drawing showing the magneto-optics system of the good light variation attenuator concerning this operation gestalt, (A) is a plan and (B) is a side elevation.
[0034] As shown in drawing 7 , a polarizer 2, the Faraday-rotation child 1, and an analyzer 3 are arranged in order along the propagation direction of the beam of light R by which outgoing radiation is carried out from the input optical fiber IN like the case of general basic composition shown in drawing 1 with the above-mentioned magneto-optics system of this adjustable optical attenuator. In this adjustable optical attenuator, each direction of the fixed magnetic field Hp given to the physical relationship and the Faraday-rotation child 1 of each optical axis of the polarizer to the direction of a beam of light and an analyzer and the adjustable magnetic field helium differs from the case of general basic composition, respectively.
[0035] The Faraday-rotation child 1 is a magneto optics crystal which has the Faraday effect which is one of the magneto-optical effects. As this magneto optics crystal, 3(RBi) (FeM)5O12 produced by the liquid-phase-epitaxial method or (RBi) 3Fe 5O12 (however, one or more sorts of elements chosen from the rare earth elements in which R contains an yttrium, one or more sorts of elements which M can replace by iron) is known, for example, and, typically, it is the becoming composition Tb1.00Y0.65Bi1.35Fe4.05Ga0.95O12. Moreover, you may be the garnet single crystal of the becoming composition Y3Fe5O12.
[0036] A polarizer 2 and an analyzer 3 are formed for example, using a wedge type rutile etc., respectively, and they are arranged so that physical relationship as each optical axis shows below may be maintained. Drawing 8 is drawing showing the physical relationship of each optical axis of the polarizer 2 in this adjustable optical attenuator, and an analyzer 3. Each optical axis shows the case where it sees from the direction shown in the arrow A of drawing 7 (A) like [here] the case where it is shown in above-mentioned drawing 2 . Moreover, about the illustrated angle, the optical axis of a polarizer 2 is made into criteria (0 degree), and the direction of counterclockwise is made positive.
[0037] As shown in drawing 8 , by this adjustable optical attenuator, arrangement of optical-axis 3a of an analyzer 3 to optical-axis 2a of a polarizer 2 is determined so that the Faraday-rotation angle thetadeltaATTmax from which the wavelength dependency of the optical magnitude of attenuation serves as the maximum may be in agreement with 0 degree of abbreviation. The optical axis (3a) of the analyzer in the general basic composition (with a parenthesis shows a corresponding sign) shown in the dashed line by drawing 8 is specifically rotated in the direction approaching optical-axis 2a of a polarizer, i.e., the direction in which angle thetap to make becomes small, and abbreviation coincidence of the dashed line which shows the Faraday-rotation angle (thetadeltaATTmax) from which the wavelength dependency of the optical magnitude of attenuation serves as the maximum is carried out on optical-axis 2a of a polarizer 2. Angle thetap at this time to make is set to angle thetapopt which was optimized here and to make.
[0038] However, even if it optimizes angle thetap made as [serve as / 0 degree of abbreviation / the Faraday-rotation angle thetadeltaATTmax from which the wavelength dependency of the optical magnitude of attenuation in general basic composition serves as the maximum depending on a setup of each parameter of this adjustable optical attenuator], the wavelength dependency of the optical magnitude of attenuation may not become the minimum. In such a case, it is desirable to optimize angle thetapopt made as [become / the minimum / a total magnitude-of-attenuation wavelength dependency].
[0039] Faraday-rotation angle thetaATTmax from which maximum Faraday-rotation angle thetamax and the maximum optical magnitude of attenuation serve as the maximum also becomes small with movement of optical-axis 3a of the

above analyzers 3. In the example of drawing 8 , Faraday-rotation angle thetaATTmax from which the optical magnitude of attenuation serves as the maximum comes to be located in a negative field. In order to realize adjustable control of such Faraday-rotation angle thetaf, it is necessary to specify the state of the magnetic field impressed to the Faraday-rotation child 1.

[0040] Drawing 9 is drawing showing the relation between the direction R of a beam of light in the good light variation attenuator of drawing 7 , the fixed magnetic field Hp, and the adjustable magnetic field helium. This illustrated relation corresponds to what expressed concretely the relation of the magnetic field shown in drawing 7 (A).

[0041] as shown in drawing 9 , while the fixed magnetic field Hp is given in parallel to the direction R of a beam of light in a good light variation attenuator, for example -- the adjustable magnetic field helium -- the direction R of a beam of light -- receiving -- 90+theta0 degree (theta0> 0) -- it shall have an angle As a concrete value of an angle theta 0, it is 15 etc. degrees etc., for example. However, the value of the angle theta 0 in this invention is not restricted to this, and can be set as arbitrary bigger angles than 0 degree.

[0042] If the vector of synthetic magnetic field helium+Hp formed of the above fixed magnetic fields Hp and the adjustable magnetic field helium intersects perpendicularly to the direction R of a beam of light, since it will be set to direction component M'=of beam of light 0 of magnetization, Faraday-rotation angle thetaf=0 degree is realized and it is set to wavelength dependency deltathetaf=0 of Faraday rotation.

[0043] When it is made to correspond to change of the size of the adjustable magnetic field helium, it explains concretely and the size of the adjustable magnetic field helium is 0, only the fixed magnetic field Hp is given to the Faraday-rotation child 1, and the greatest Faraday-rotation angle thetamax is obtained by the saturation magnetization M parallel to a ray axis. When the size of the adjustable magnetic field helium increases in helium1, synthetic magnetic field helium1+Hp is given to the Faraday-rotation child 1, and positive Faraday-rotation angle thetaf (<thetamax) according to direction component of beam of light M' (> 0) of Magnetization M is obtained. Moreover, when the size of the adjustable magnetic field helium increases in helium2, synthetic magnetic field helium2+Hp which intersects perpendicularly with a ray axis is given to the Faraday-rotation child 1, direction component of beam of light M' of Magnetization M is set to 0, and Faraday-rotation angle thetaf is also set to 0. In the state of this adjustable magnetic field helium 2, the wavelength dependency deltathetaf of a Faraday-rotation angle becomes the smallest. Furthermore, when the size of the adjustable magnetic field helium increases in helium3, synthetic magnetic field helium3+Hp is given to the Faraday-rotation child 1, and negative Faraday-rotation angle thetaf according to direction component of beam of light M' (<0) of Magnetization M is obtained. Here, as shown in above-mentioned drawing 8 , the maximum optical magnitude of attenuation is realized in the field to which Faraday-rotation angle thetaf becomes negative.

[0044] Here, the composition as a magnetic field generating means for giving the Faraday-rotation child 1 the above fixed magnetic fields Hp and the adjustable magnetic field helium is explained briefly. Drawing 10 is the perspective diagram showing the concrete example of composition which gives the Faraday-rotation child 1 a magnetic field in this adjustable optical attenuator.

[0045] In the example of composition of drawing 10 , the circular permanent magnets 11 and 12 arrange polarity on the ray axis located before and after the Faraday-rotation child 1, are arranged, respectively, and generate the fixed magnetic field Hp, for example. Moreover, the yoke of an electromagnet 13 is arranged so that the Faraday-rotation child 1 may be inserted, and according to the force current I to this electromagnet 13, the adjustable magnetic field helium of a necessary size occurs.

[0046] Based on the principle of operation which was mentioned above, by carrying out adjustable control of the force current I to an electromagnet 13, Faraday-rotation angle thetaf is adjusted and the quantity of light combined with the output optical fiber OUT is controlled by such good light variation attenuator of composition. Since the magneto-optics system is optimized in consideration of [that wavelength dependency deltaATT of the optical magnitude of attenuation in this adjustable optical attenuator mentioned above] the wavelength dependency of a Faraday-rotation angle at this time, it will decrease sharply.

[0047] Drawing 11 is drawing showing the result which computed the relation between Faraday-rotation angle thetaf in the good light variation attenuator of this operation gestalt, and force current I. Moreover, drawing 12 is drawing showing the result which computed the relation of the optical magnitude of attenuation ATT and force current I which were made to correspond to drawing 11 using above-mentioned (1) formula. However, the value shown in the horizontal axis and vertical axis of drawing 11 is the same as that of the case of drawing 4 mentioned above, and the value shown in the horizontal axis and vertical axis of drawing 12 is the same as that of the case of drawing 5 mentioned above.

[0048] In calculation of the relation shown in each drawing, the angle which makes an angle theta 0 15 degrees and the adjustable magnetic field helium to the direction of a beam of light makes, for example was set as 105 degrees, and the maximum ER of the optical magnitude of attenuation was set as 25dB. Moreover, angle thetapopt which attained

optimization based on temperature dependence deltaATT of the optical magnitude of attenuation shown in drawing 5 was used for angle thetap which each opticals axis 2a and 3a of a polarizer 2 and an analyzer 3 make.

[0049] As shown in drawing 11 , in this adjustable optical attenuator, it turns out that the point that Faraday-rotation angle thetaf becomes 0 degree has arisen by having set the angle which the adjustable magnetic field helium to the direction of a beam of light makes as 105 degrees. Specifically, when force current I is set up near about 40mA, Faraday-rotation angle thetaf becomes 0 degree, and the wavelength dependency deltathetaf has become the minimum. As shown in drawing 12 , when this sets up force current I near about 40mA, it turns out that wavelength dependency deltaATT of the optical magnitude of attenuation is once the minimum. Moreover, when it is set as about 60mA, it comes to realize the state where the optical magnitude of attenuation serves as the maximum by having set to thetapopt the angle which each opticals axis 2a and 3a of a polarizer 2 and an analyzer 3 make, and Faraday-rotation angle thetaATTmax in this state has become the negative value of about -7 degrees from drawing 11 .

[0050] Generally, since the range to which the optical magnitude of attenuation is carrying out the monotonous increase (or reduction) of the good light variation attenuator serves as a use region, in an optical damping property like drawing 12 , the range whose force current I is about 0-60mA will be equivalent to a use region. Such wavelength dependency deltaATT of the optical magnitude of attenuation about a use region is once set to 0dB near 40mA of use region middle, and has become a small value of about 0.26dB at the maximum. Compared with the maximum in the area within use of temperature dependence deltaATT of the optical magnitude of attenuation shown in drawing 5 having been about 1.1dB, it turns out that the wavelength dependency of this adjustable optical attenuator is reduced sharply.

[0051] As mentioned above, according to this operation form, in consideration of the wavelength dependency deltathetaf of Faraday-rotation angle thetaf, reduction-ization of wavelength dependency deltaATT of the optical magnitude of attenuation can be attained by optimizing arrangement of each opticals axis 2a and 3a of a polarizer 2 and an analyzer 3. Moreover, it becomes possible by specifying the direction of the fixed magnetic field Hp to the direction of a beam of light, and the adjustable magnetic field helium to carry out 0 degree Faraday-rotation angle thetaf. Since the optical magnitude of attenuation is realized within limits which change in monotone from 0 to maximum, the state where this Faraday-rotation angle thetaf becomes 0 degree can make small wavelength dependency deltaATT of the optical magnitude of attenuation covering all the use regions of a good light variation attenuator. It is useful to build various kinds of lightwave transmission systems using the good light variation attenuator by which such a wavelength dependency was reduced.

[0052] In addition, although each opticals axis 2a and 3a of a polarizer 2 and an analyzer 3 were optimized with the operation form mentioned above so that the Faraday-rotation angle thetadeltaATTmax from which the wavelength dependency of the optical magnitude of attenuation becomes the maximum might serve as 0 degree of abbreviation this invention can acquire the reduction effect of the wavelength dependency of the optical magnitude of attenuation by not being restricted to this, and changing arrangement of each opticals axis 2a and 3a so that the Faraday-rotation angle thetadeltaATTmax in general basic composition may become as small as possible.

[0053] For example, angle thetap which a polarizer 2 and an analyzer 3 make is changed into 100 degrees from 105 degrees (composition of drawing 2), and the case where only 5 degrees of Faraday-rotation angles thetadeltaATTmax are close brought in the direction of 0 degree is considered.

[0054] Drawing 13 is drawing showing the result which computed the relation between Faraday-rotation angle thetaf in above-mentioned, and force current I. Moreover, drawing 14 is drawing showing the result which computed the relation of the optical magnitude of attenuation ATT and force current I which were made to correspond to drawing 13 using above-mentioned (1) formula.

[0055] Although the Faraday-rotation angle thetadeltaATTmax cannot be made into 0 degree only by making angle thetap to make small at 100 degrees as shown in drawing 13 , as shown in drawing 14 , it turns out that wavelength dependency deltaATT of the optical magnitude of attenuation in the area within use can be reduced to about 0.8dB or less.

[0056] Moreover, although it set up with the operation form mentioned above so that it might become a relation as showed the direction R of a beam of light, the fixed magnetic field Hp, and the adjustable magnetization helium to drawing 9 , application as not restricted to this and shown in drawing 15 or drawing 16 is also possible for this invention.

[0057] In the example of drawing 15 , while the direction R of a beam of light, and theta0 degree of fixed magnetic fields Hp are leaned to the Faraday-rotation child's 1 medial axis (alternate long and short dash line of drawing), let the adjustable magnetic field helium be the direction which intersects perpendicularly with the Faraday-rotation child's 1 medial axis. Like the case where it is shown in drawing 9 also as a relation of such a magnetic field, when the size of the adjustable magnetic field helium is set to helium2, synthetic magnetic field helium2+Hp which intersects

perpendicularly in the direction of a beam of light is given to the Faraday-rotation child 1, the direction component of a beam of light of Magnetization M is set to 0, and Faraday-rotation angle thetaf is also set to 0.

[0058] In the example of drawing 16 , the theta0 degree of the directions R of a beam of light is leaned to the Faraday-rotation child's 1 medial axis (alternate long and short dash line of drawing), the fixed magnetic field Hp is made into a direction parallel to the Faraday-rotation child's 1 medial axis, and it considers as the direction where the Faraday-rotation child's 1 medial axis and the adjustable magnetic field helium cross at right angles. That is, when leaning R thetheta0 degree of the directions of a beam of light, the direction of the fixed magnetic field Hp is an example that it is not necessary to necessarily lean. This is decided by the size of the magnetization to which Faraday-rotation angle thetaf met in the direction of a beam of light, and if enough for direction component Hpof beam of light' of the fixed magnetic field Hp to saturate the Faraday-rotation child's 1 magnetization, it shows that it is not necessary to lean the fixed magnetic field Hp.

[0059] What is necessary is just to choose suitably arrangement of the magnetic field shown in drawing 9 , above-mentioned drawing 15 , or above-mentioned drawing 16 in consideration of each feature, in case this adjustable optical attenuator is device-ized. Specifically, the method (drawing 15 , drawing 16) to which the direction of a beam of light is inclined means also inclining an I/O optical fiber, and since there is a possibility of being hard that it may come to mount as a device, it is careful of it. Moreover, to the Faraday-rotation child 1, the method (drawing 9) to which the adjustable magnetic field helium is inclined to the Faraday-rotation child 1 needs to devise the configuration of a yoke etc. so that the magnetic field of an electromagnet 13 may be impressed to an optimum from the method of slanting. For example, measures, such as enlarging a yoke, are needed, and since a device may become large, it is careful. In addition, the method (drawing 16) to which only the direction of a beam of light is inclined becomes possible [device-izing using the permanent magnet of configurations, such as not the permanent magnet of the shape of a ring as shown in drawing 10 but the shape of a pillar, and a rectangular parallelepiped,]. For example, since the pillar-like permanent magnet generally has the stable magnetic field on the center line, the fixed magnetic field Hp by the permanent magnet tends to be stabilized, and this has the advantage of leading to stabilization of the property of a good light variation attenuator.

[0060] Furthermore, although the operation gestalt mentioned above showed the case where an angle theta 0 was set as 15 degrees, this invention is not restricted to this setup. For example, theta 0 is enlarged, it changes into 20 degrees, and the case where other setup is made the same is considered.

[0061] Drawing 17 is drawing showing the result which computed the relation between Faraday-rotation angle thetaf in above-mentioned, and force current I. Moreover, drawing 18 is drawing showing the result which computed the relation of the optical magnitude of attenuation ATT and force current I which were made to correspond to drawing 17 using above-mentioned (1) formula.

[0062] Although it is almost changeless with it when wavelength dependency deltaATT of the optical magnitude of attenuation when considering as theta0=20 degree considers as theta0=15 degree as shown in drawing 18 , the current value which generates the maximum optical magnitude of attenuation ATT is decreasing from about 60mA to 40mA. This means that reduction of the power consumption as a good light variation attenuator is achieved by setting up an angle theta 0 as greatly as possible within limits which can secure the precision required of adjustable control of the optical magnitude of attenuation ATT.

[0063] In addition, although the case where the maximum optical magnitude of attenuation ER was set as 25dB was shown, it is possible to set up arbitrarily also about this setup. For example, the case where set the maximum optical magnitude of attenuation ER to 30dB, and other setup is made the same is considered.

[0064] Drawing 19 is drawing showing the result which computed the relation between Faraday-rotation angle thetaf in above-mentioned, and force current I. Moreover, drawing 20 is drawing showing the result which computed the relation of the optical magnitude of attenuation ATT and force current I which were made to correspond to drawing 19 using above-mentioned (1) formula.

[0065] As shown in drawing 20 , the maximum of wavelength dependency deltaATT of the optical magnitude of attenuation when being referred to as ER=30dB is about 0.57dB, and is increasing compared with the time (drawing 12) of being referred to as-25dB. However, an intermediary can also reduce optimized angle thetapopt to make by optimizing again to increase of this wavelength dependency deltaATT. It is specifically setting up about several degrees angle thetapopt to make greatly, and increase of wavelength dependency deltaATT of the optical magnitude of attenuation when enlarging ER can be reduced.

[0066] Drawing 21 and drawing 22 are drawings showing the property when optimizing angle thetapopt to make again as ER=30dB. Moreover, the property when optimizing angle thetapopt to make again as ER=40dB is also shown in drawing 23 and drawing 24 . As shown in each drawing, when a setup of the maximum light magnitude of attenuation ER is changed, it is possible to fully reduce wavelength dependency deltaATT of the optical magnitude of attenuation

by optimizing angle thetap which each optical axis of a polarizer 2 and an analyzer 3 makes according to this setup. However, it is cautious of there being an inclination for wavelength dependency deltaATT of the optical magnitude of attenuation to increase, so that the maximum light magnitude of attenuation ER is enlarged. The maximum of wavelength dependency deltaATT according to each setup of the maximum light magnitude of attenuation ER becomes like 0.26dB (-25dB), 0.31dB (ER=30dB), and 0.34dB (ER=40dB).

[0067] In addition, what is considered in relation to the above-mentioned inclination when wavelength dependency deltaATT of the optical magnitude of attenuation does not need to be reduced in all the ranges of the maximum magnitude of attenuation ER from 0dB is explained briefly.

[0068] For example, the optical level adjustment which uses for the shutdown function in the emergency of an optical-transmission device etc. maximum light magnitude-of-attenuation ER=40dB, and is usually used at the time of employment can assume the case where the optical magnitude of attenuation is about 20dB. In such a case, the range which should take into consideration wavelength dependency deltaATT of the optical magnitude of attenuation is for 0-20dB, and the size of wavelength dependency deltaATT is not asked at the time of the shutdown of light. Therefore, when it is useful to decide the range of the optical magnitude of attenuation ATT in consideration of wavelength dependency deltaATT of the optical magnitude of attenuation as a good light variation attenuator, it thinks.

[0069] Drawing 25 and drawing 26 are drawings showing the result which computed the property supposing the case of being above, by having limited the reduction range of the wavelength dependency of the optical magnitude of attenuation to 0-20dB in ER=40dB. As shown in drawing 26 , it turns out that the maximum of wavelength dependency deltaATT of the optical magnitude of attenuation [in / the range of 20dB or less / in the optical magnitude of attenuation ATT] is about 0.24dB, and reduction-ization of wavelength dependency deltaATT is attained as compared with the case of a setup shown in drawing 24 .

[0070]

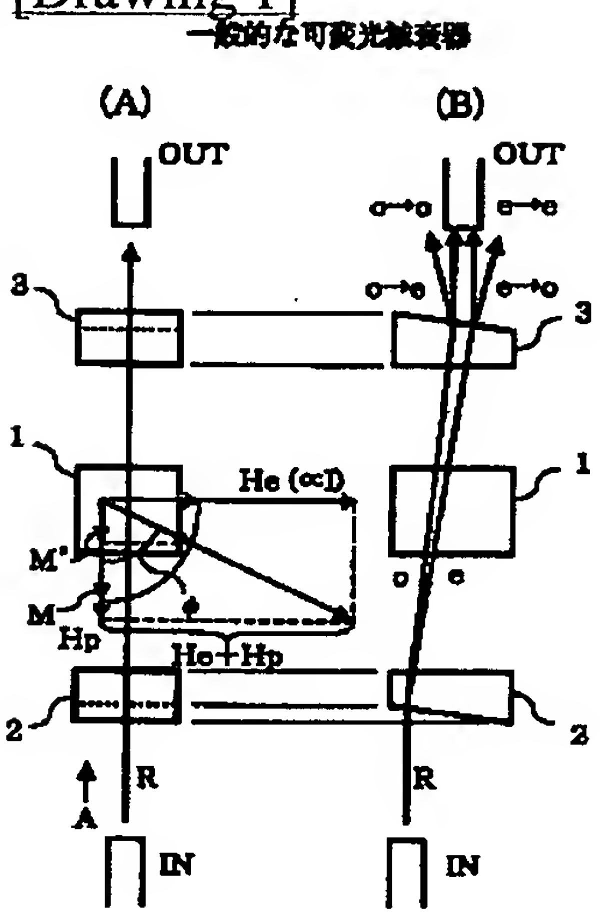
[Effect of the Invention] As explained above, the good light variation attenuator using the Faraday effect of this invention can attain reduction-ization of the wavelength dependency of the optical magnitude of attenuation by setting up the angle which each optical axis of the element which starts the linearly polarized light makes in consideration of the wavelength dependency of a Faraday-rotation angle. Moreover, by specifying each direction of a fixed magnetic field and an adjustable magnetic field about a magnetic field generating means, since a setup at 0 degree is attained in a Faraday-rotation angle, the wavelength dependency of the optical magnitude of attenuation can be reduced more. If various lightwave transmission systems, such as a WDM lightwave transmission system, are constituted using the good light variation attenuator by which such a wavelength dependency was reduced, it will become possible to realize the stable optical transmission.

[Translation done.]

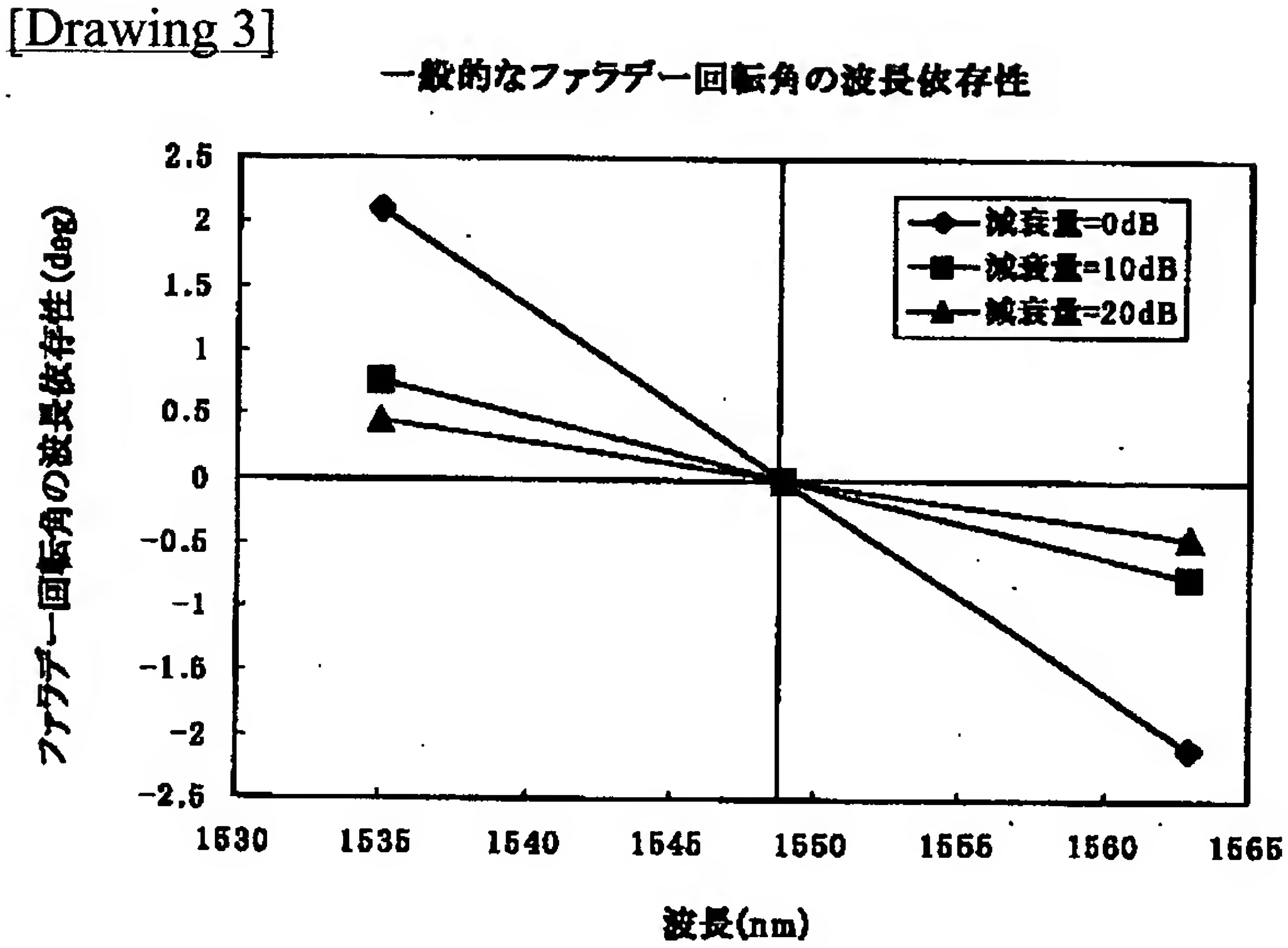
* NOTICES *

DRAWINGS

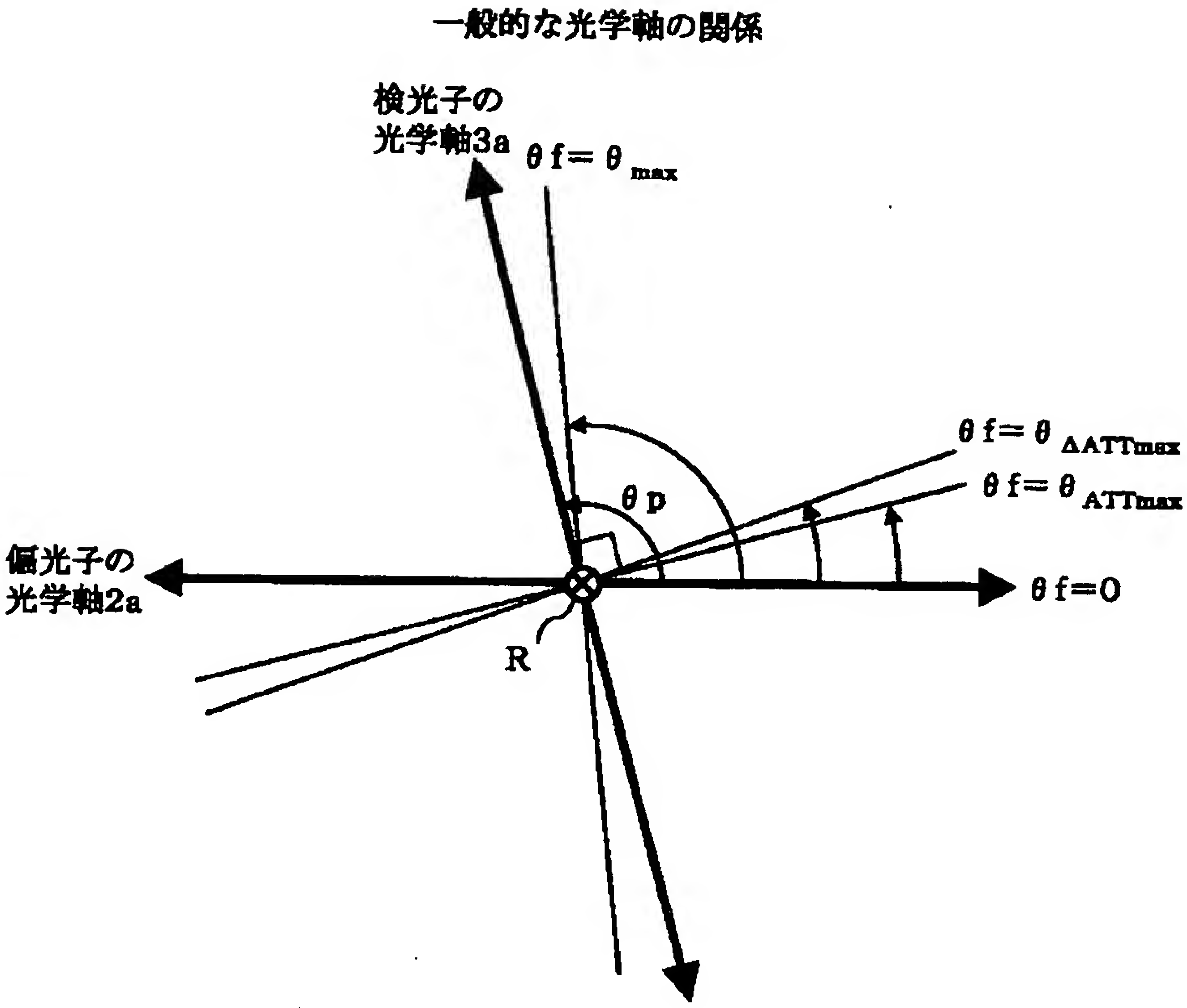
[Drawing 1]



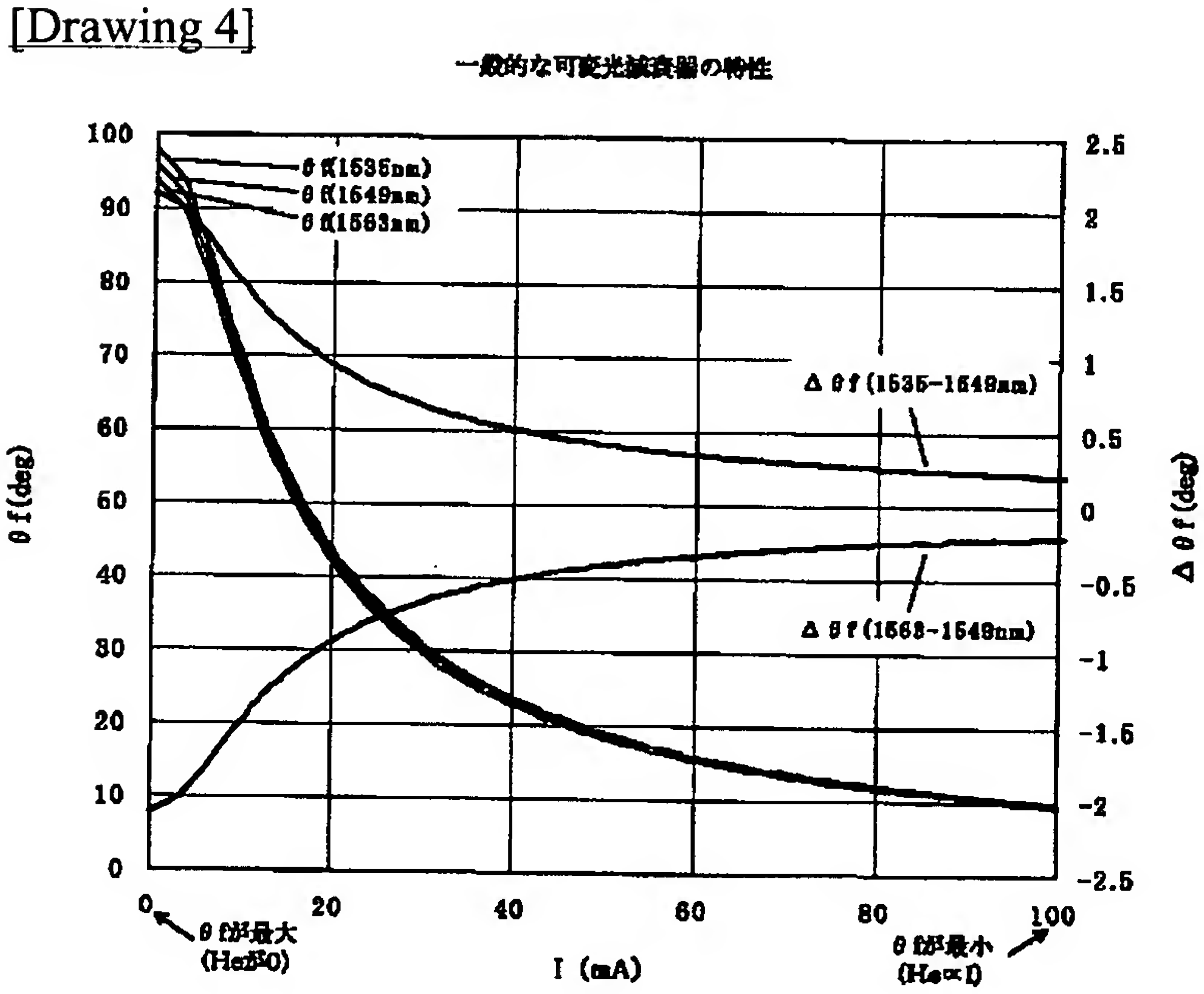
[Drawing 3]



[Drawing 2]

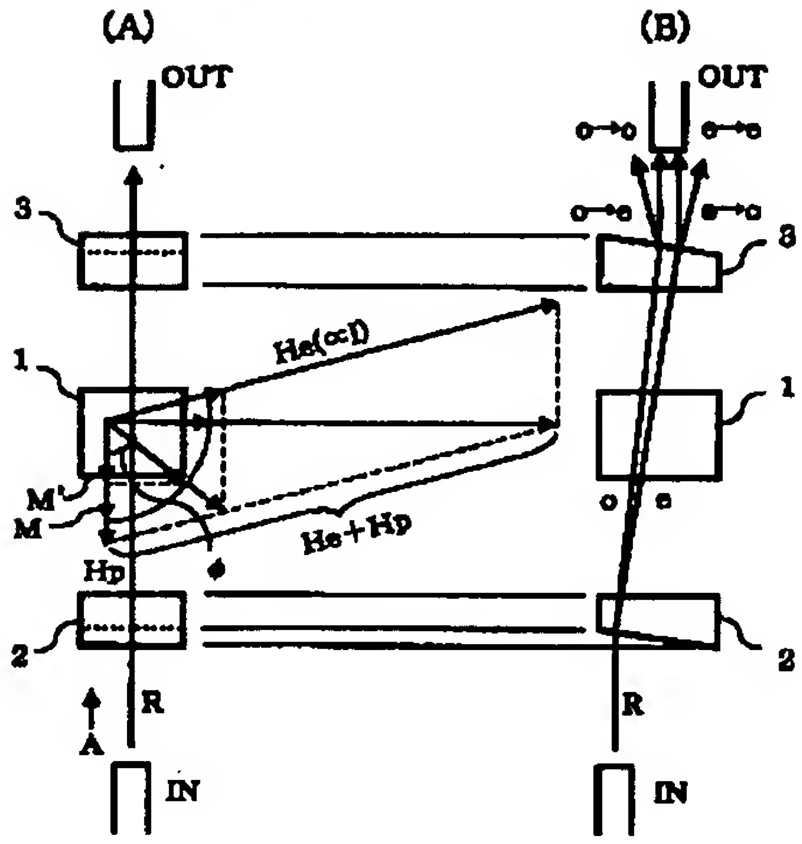


[Drawing 4]



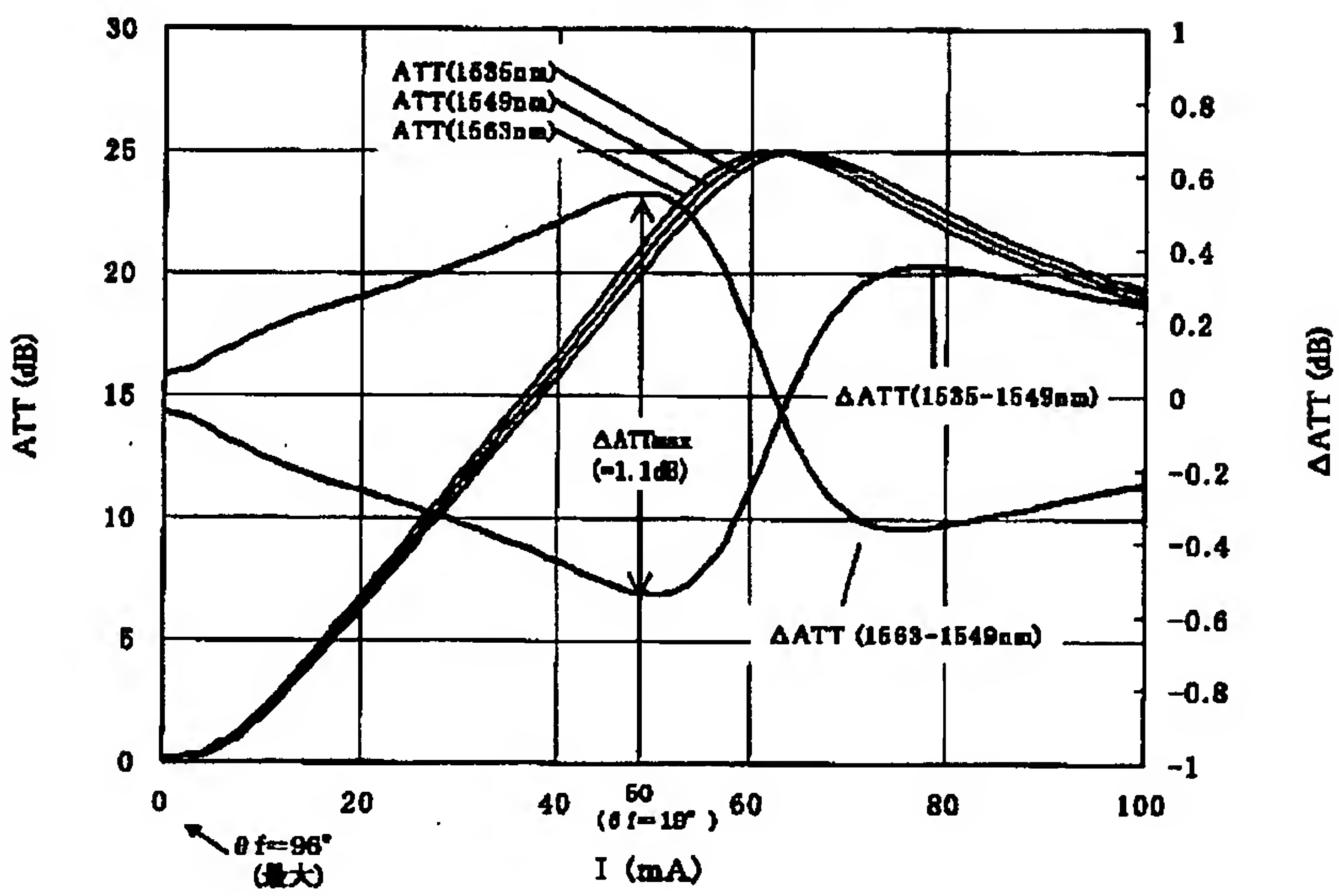
[Drawing 7]

本実施形態の可変光減衰器



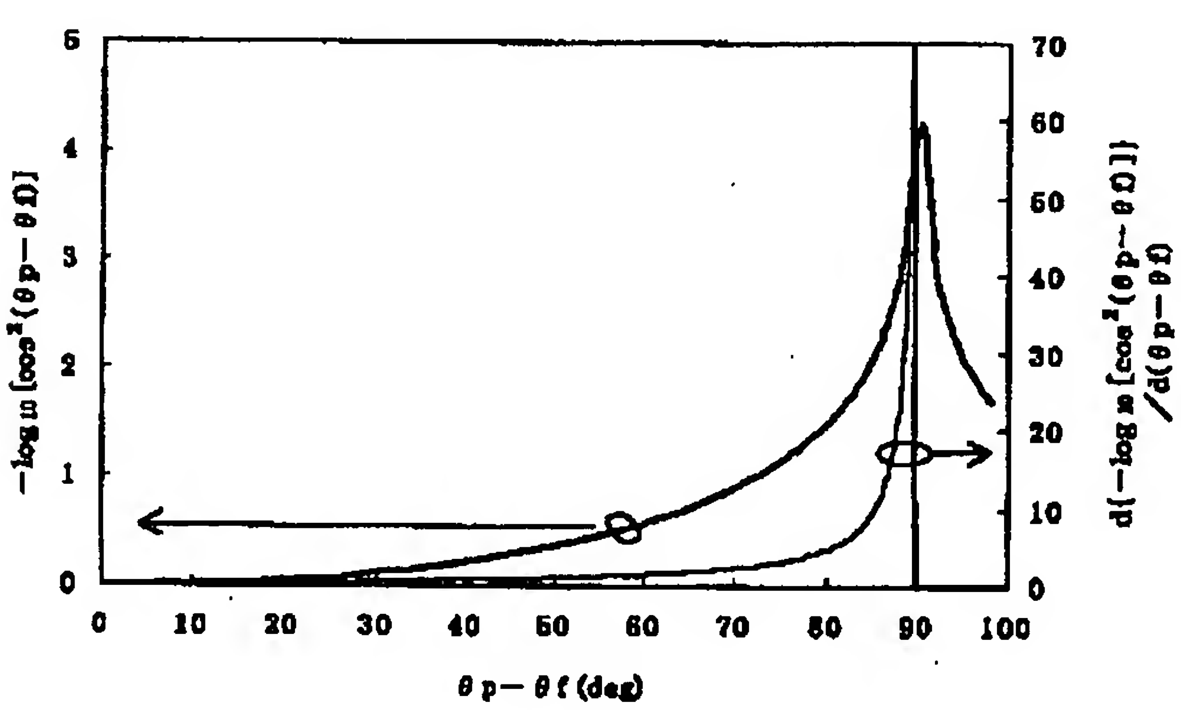
[Drawing 5]

一般的な可変光減衰器の特性



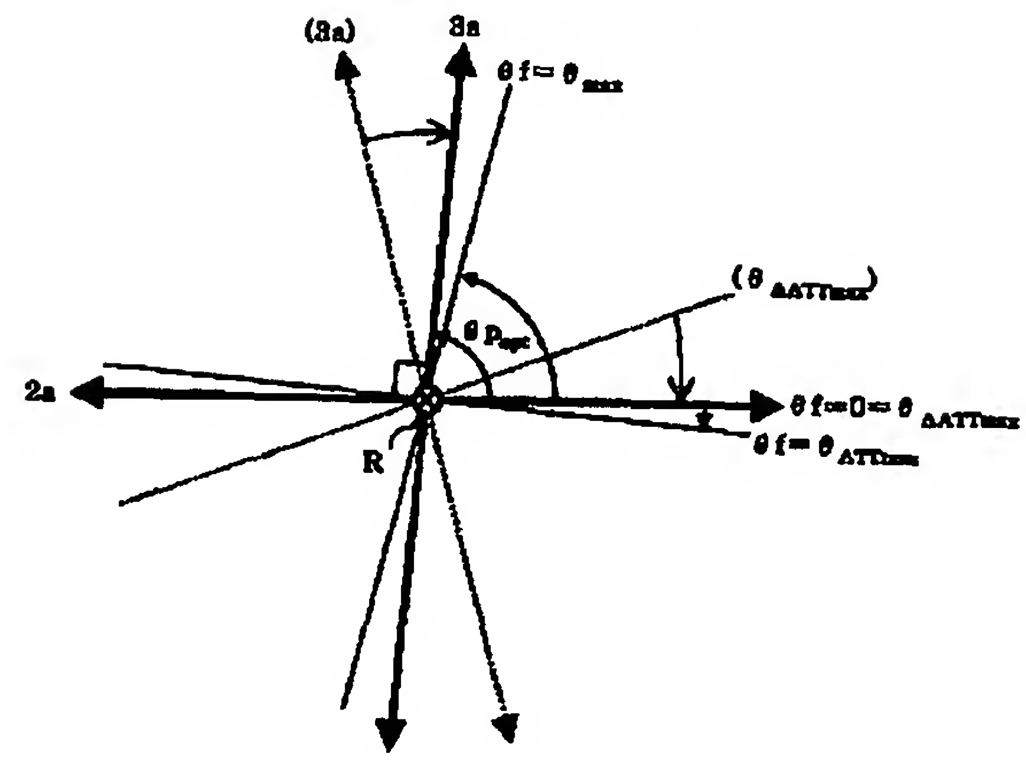
[Drawing 6]

一般的な可変光減衰器の特性



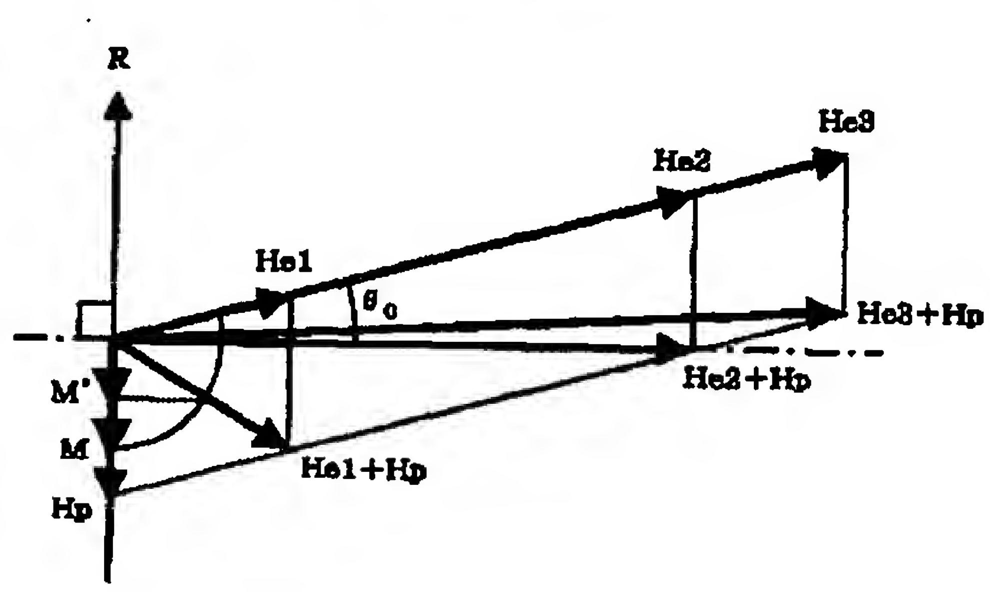
[Drawing 8]

本実施形態の光学軸の関係

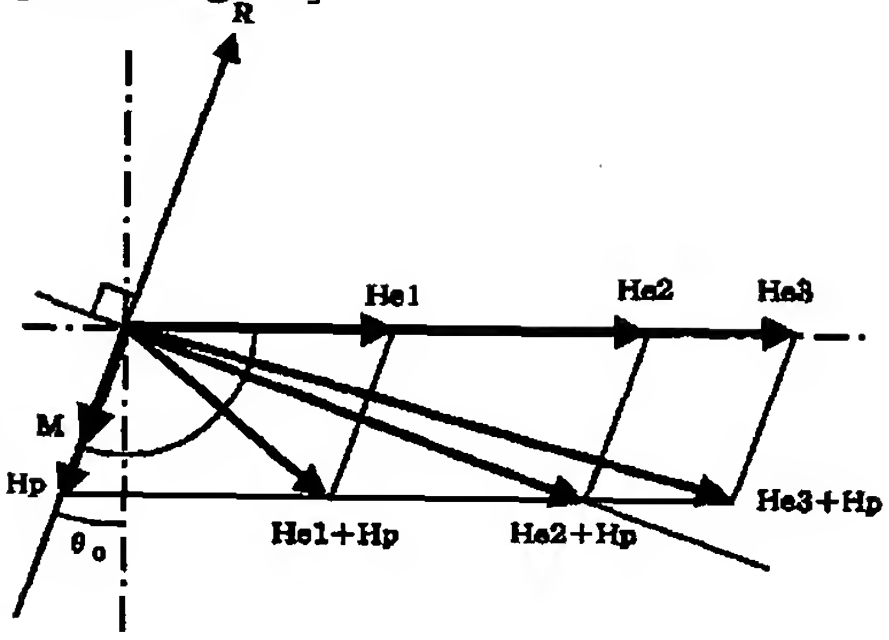


[Drawing 9]

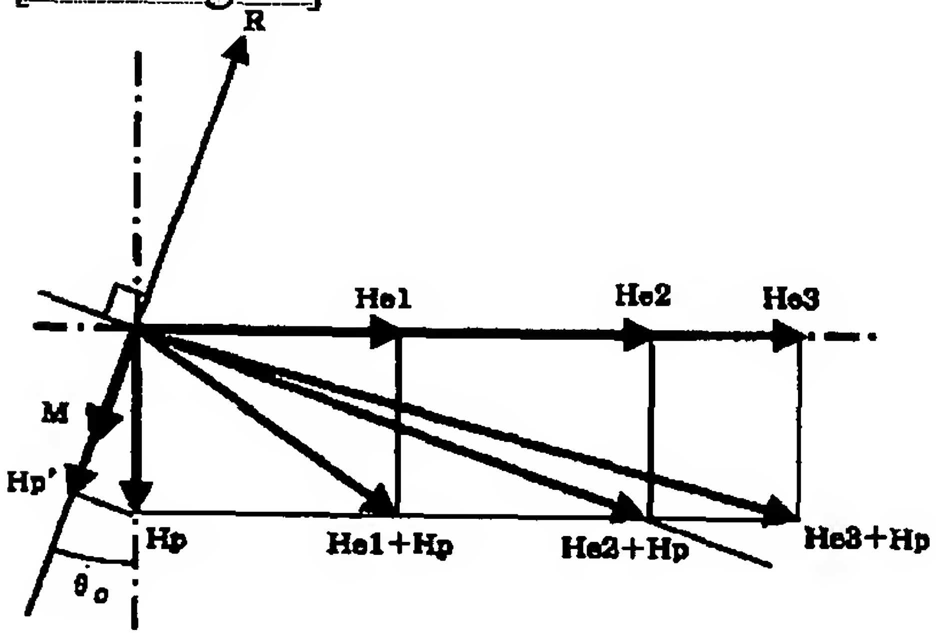
本実施形態の磁場の関係



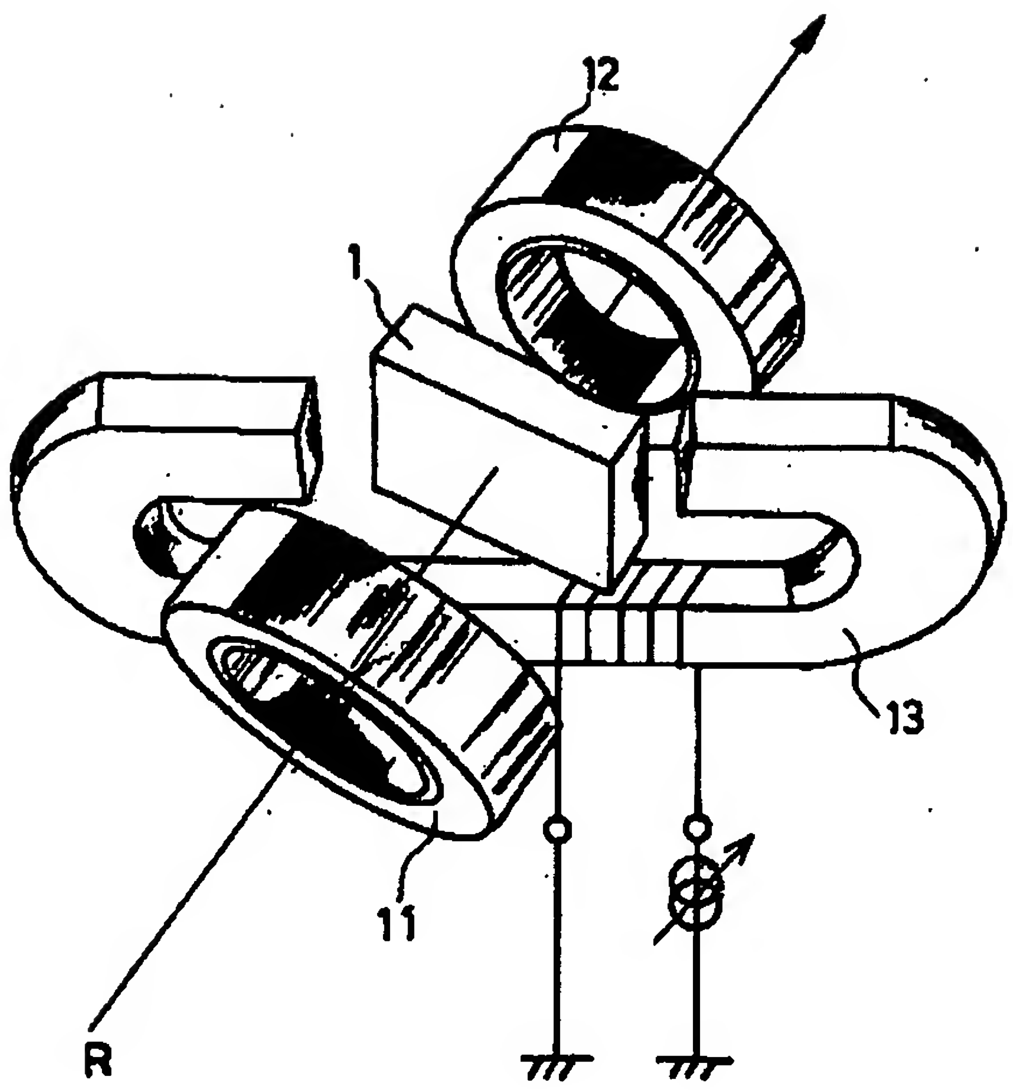
[Drawing 15]



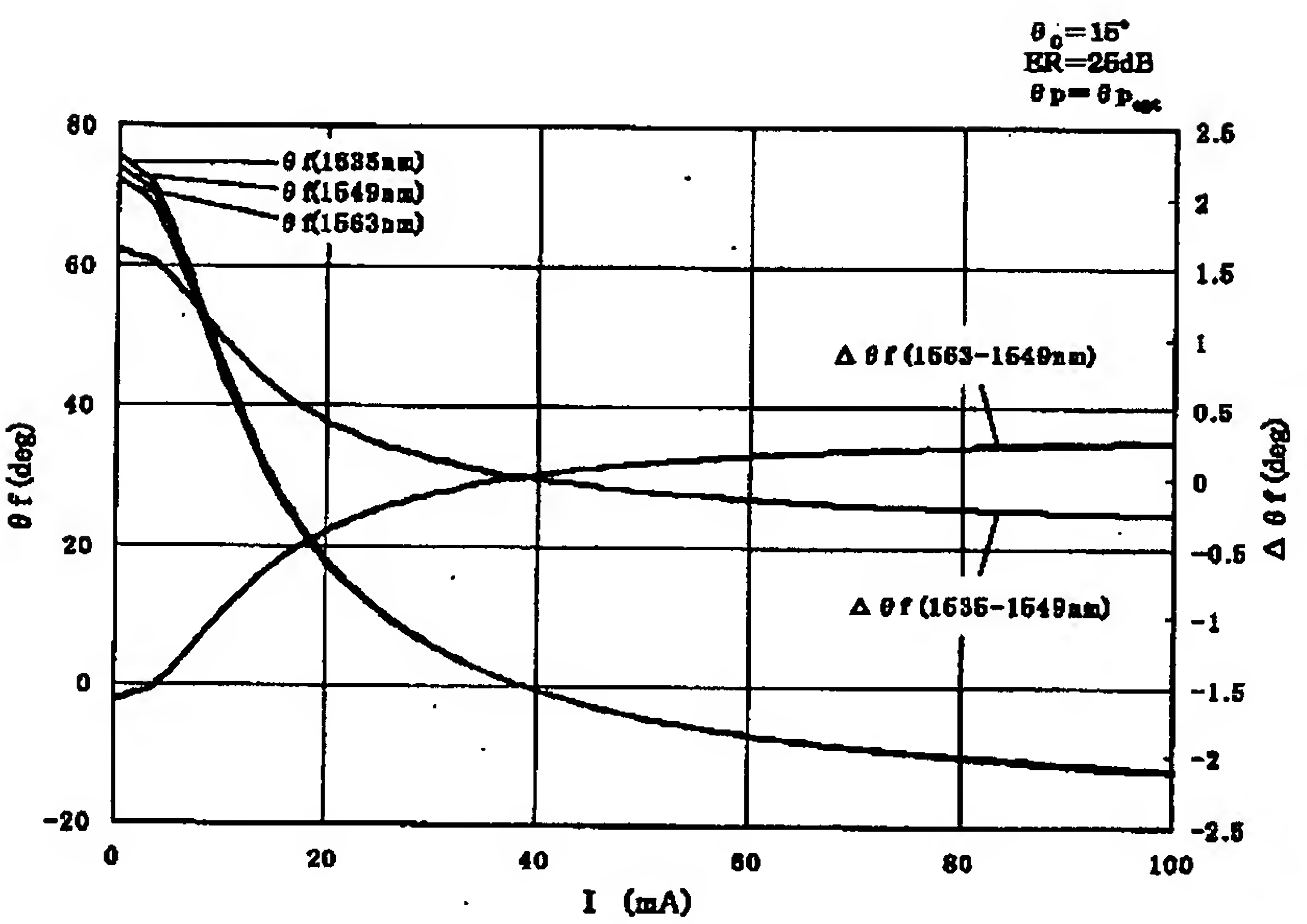
[Drawing 16]



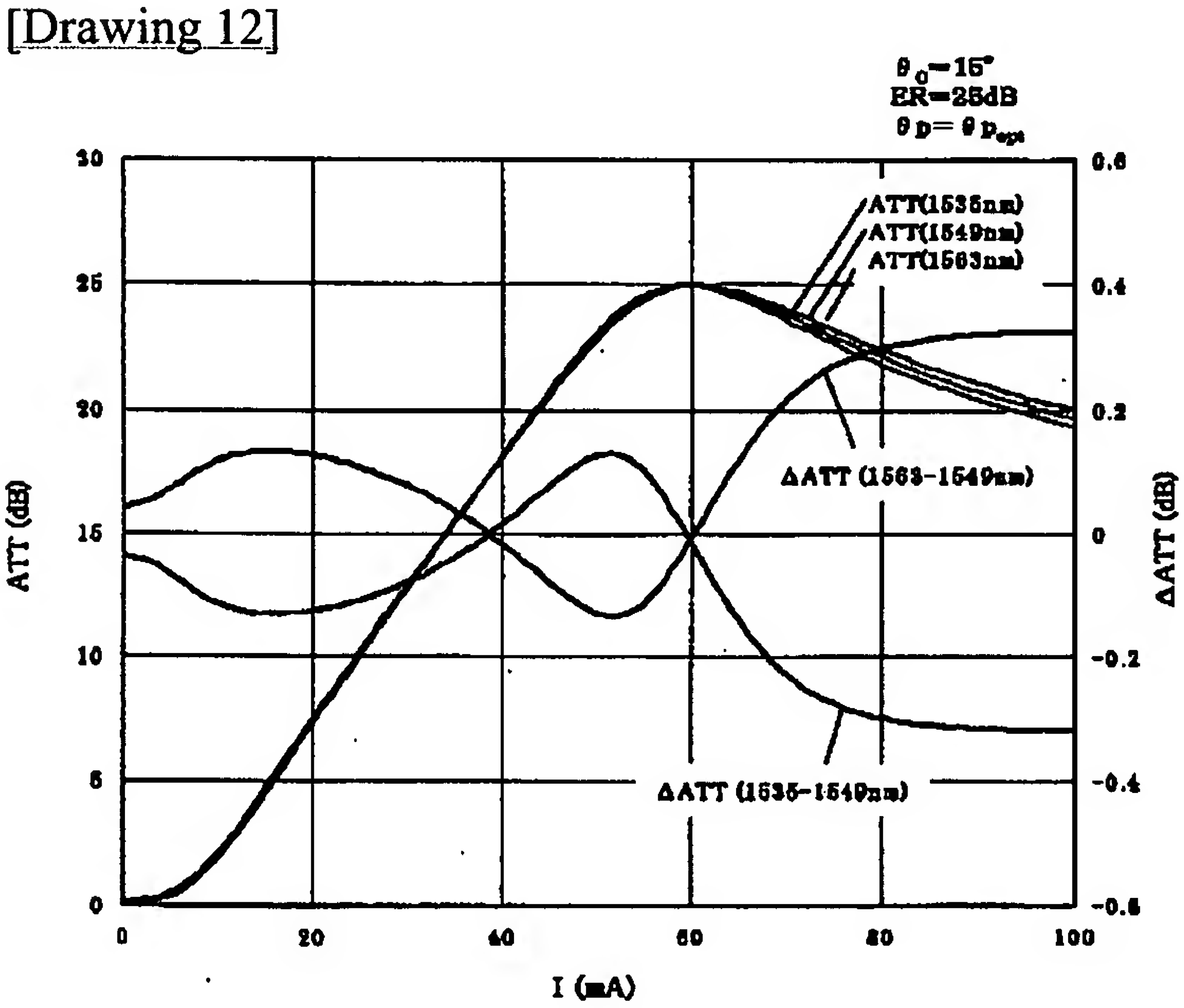
[Drawing 10]



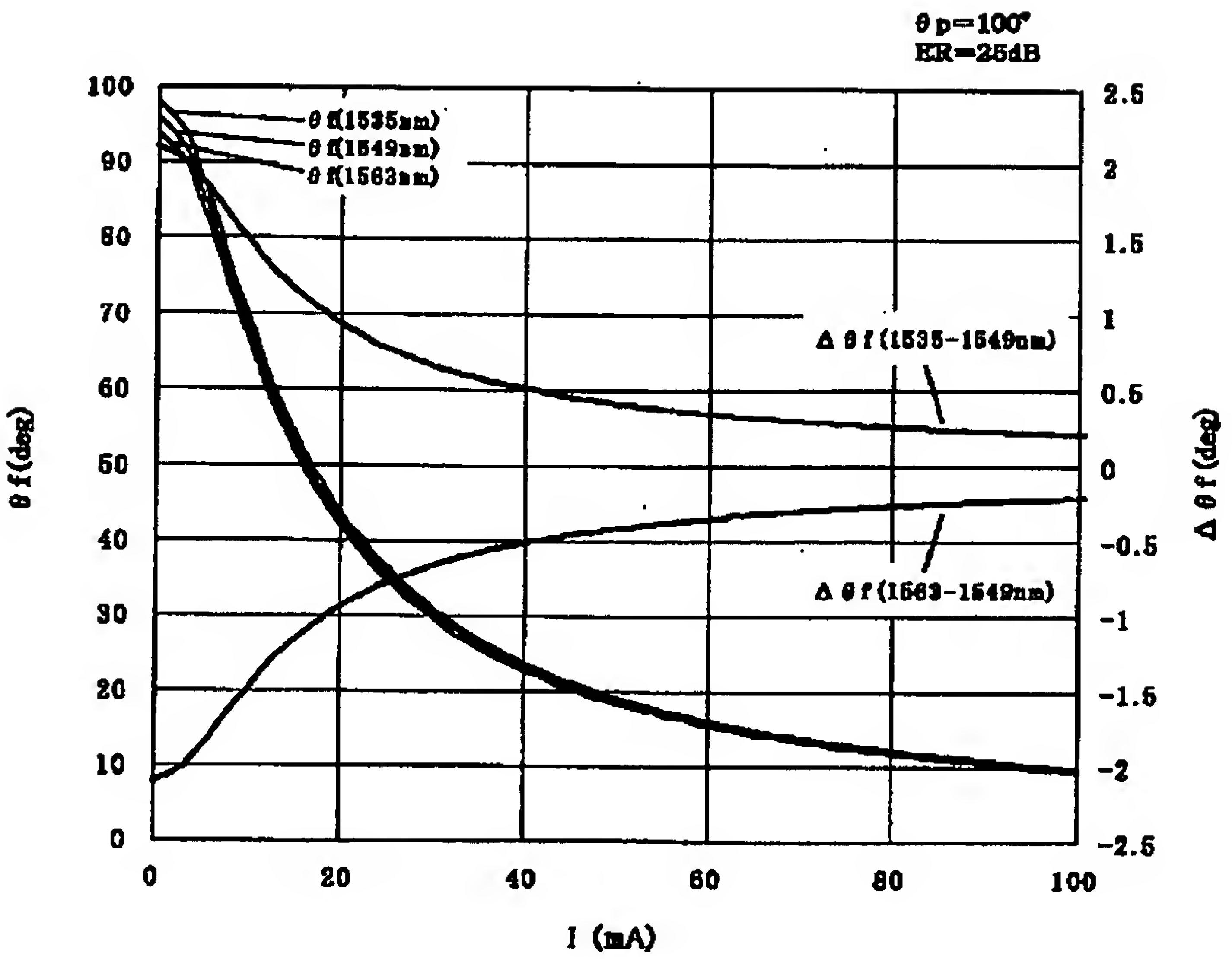
[Drawing 11]



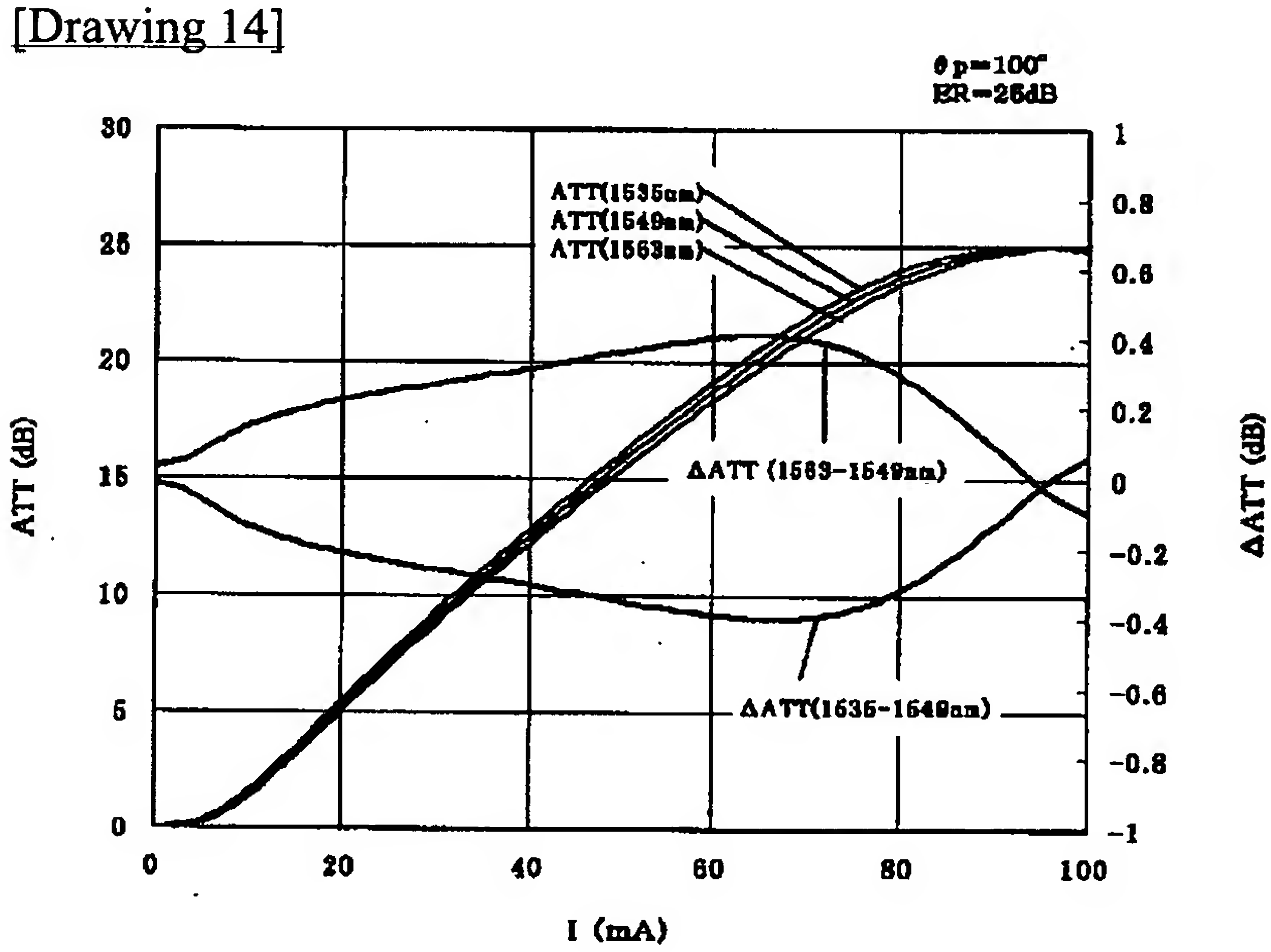
[Drawing 12]



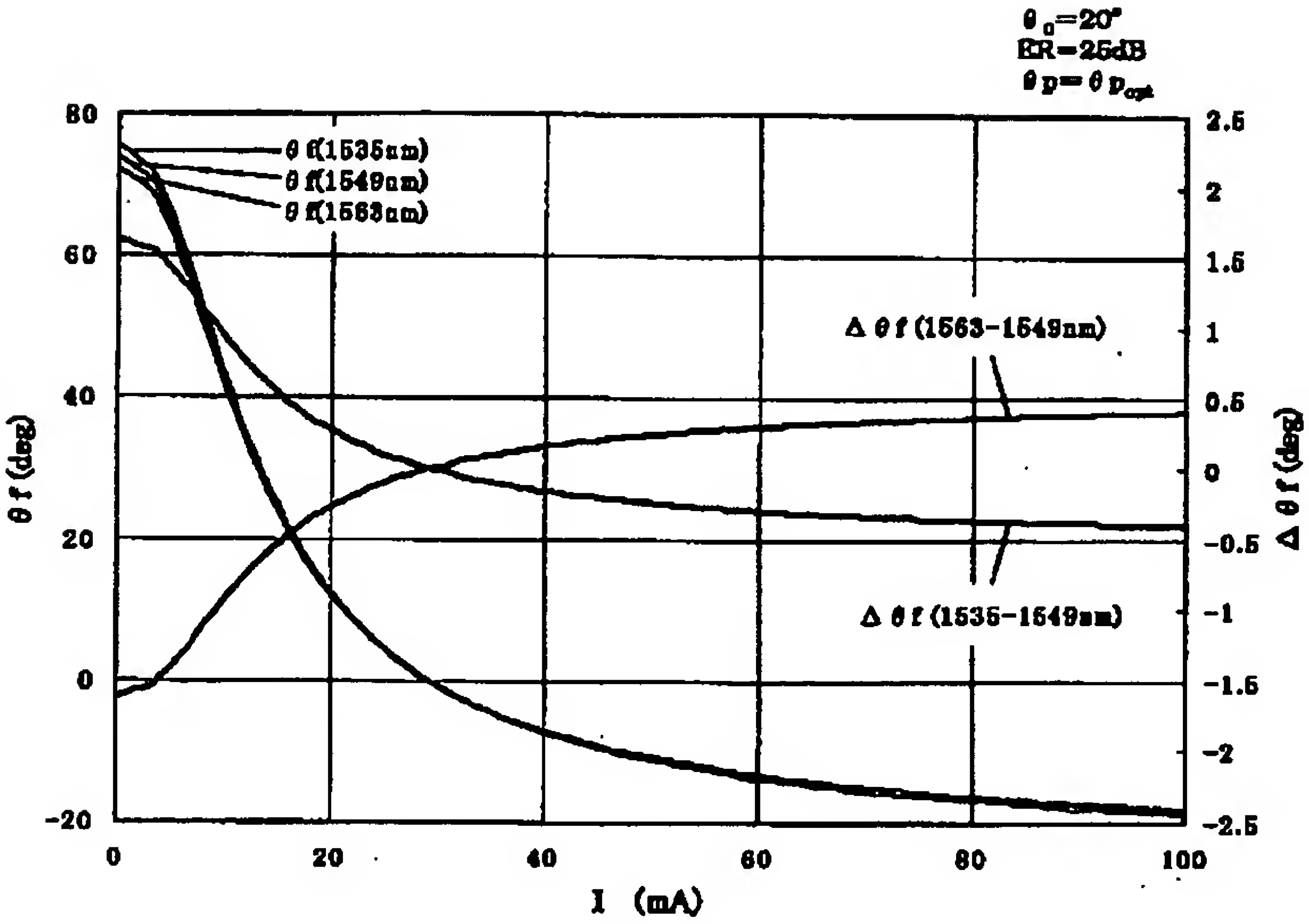
[Drawing 13]



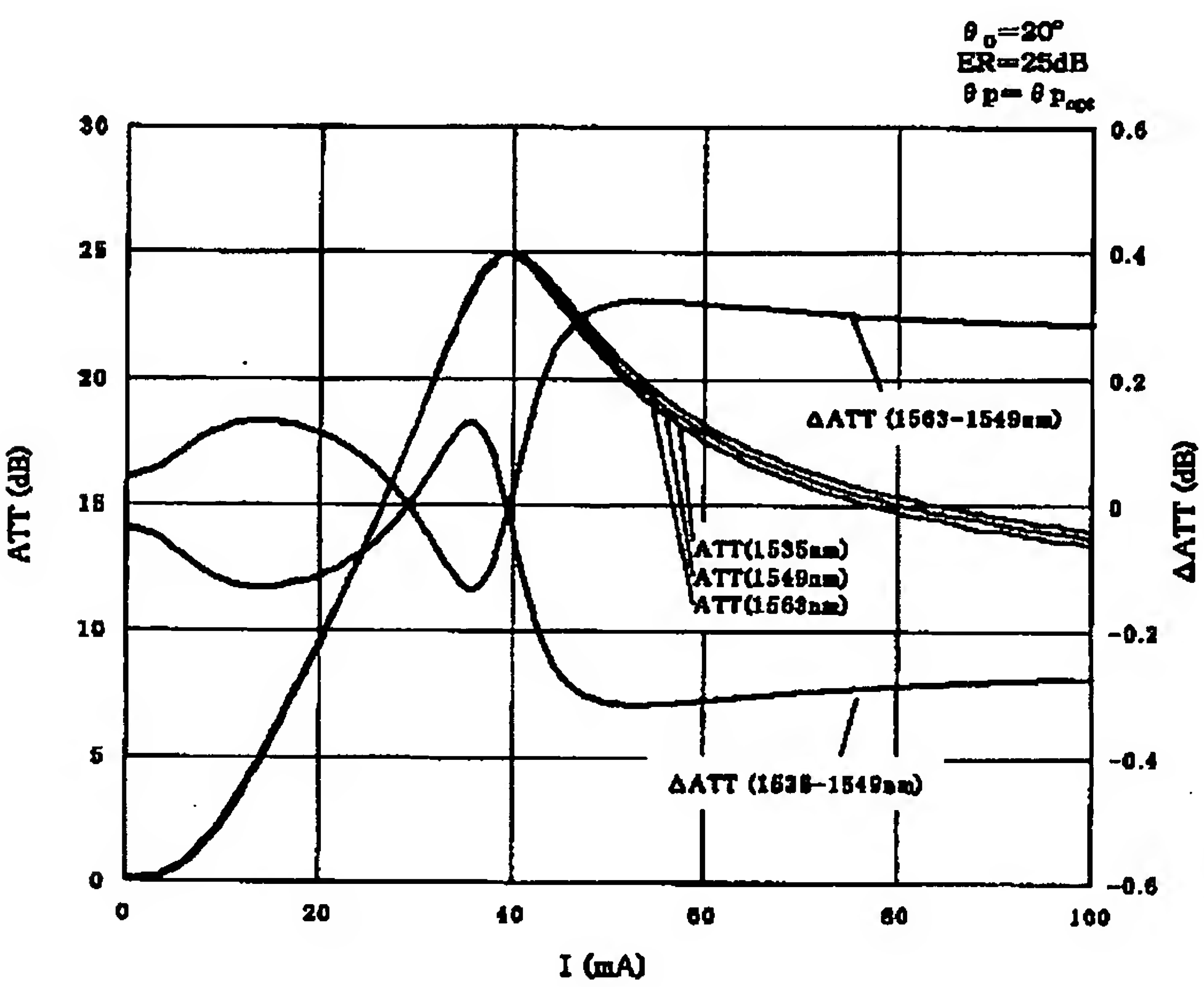
[Drawing 14]



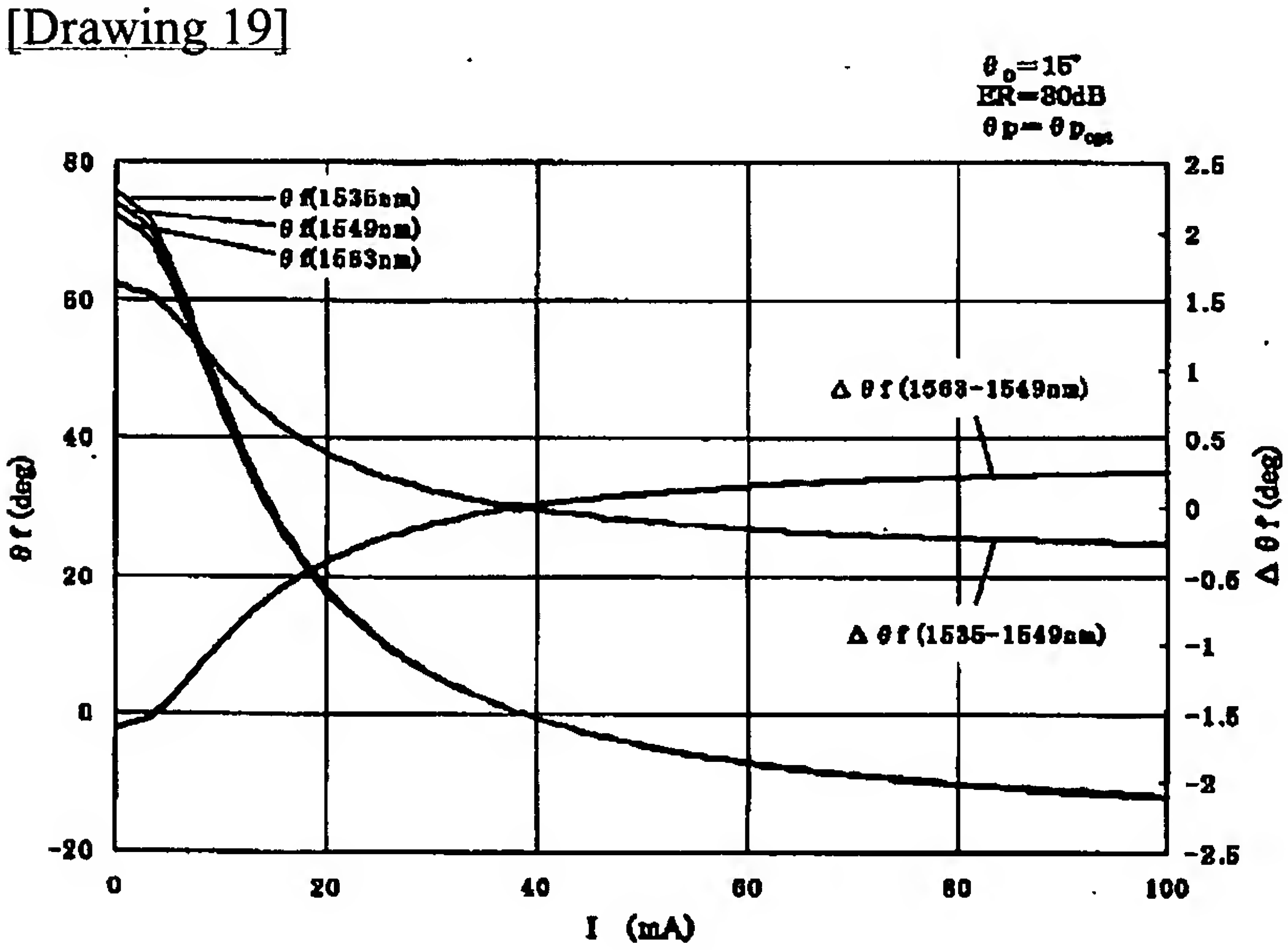
[Drawing 17]



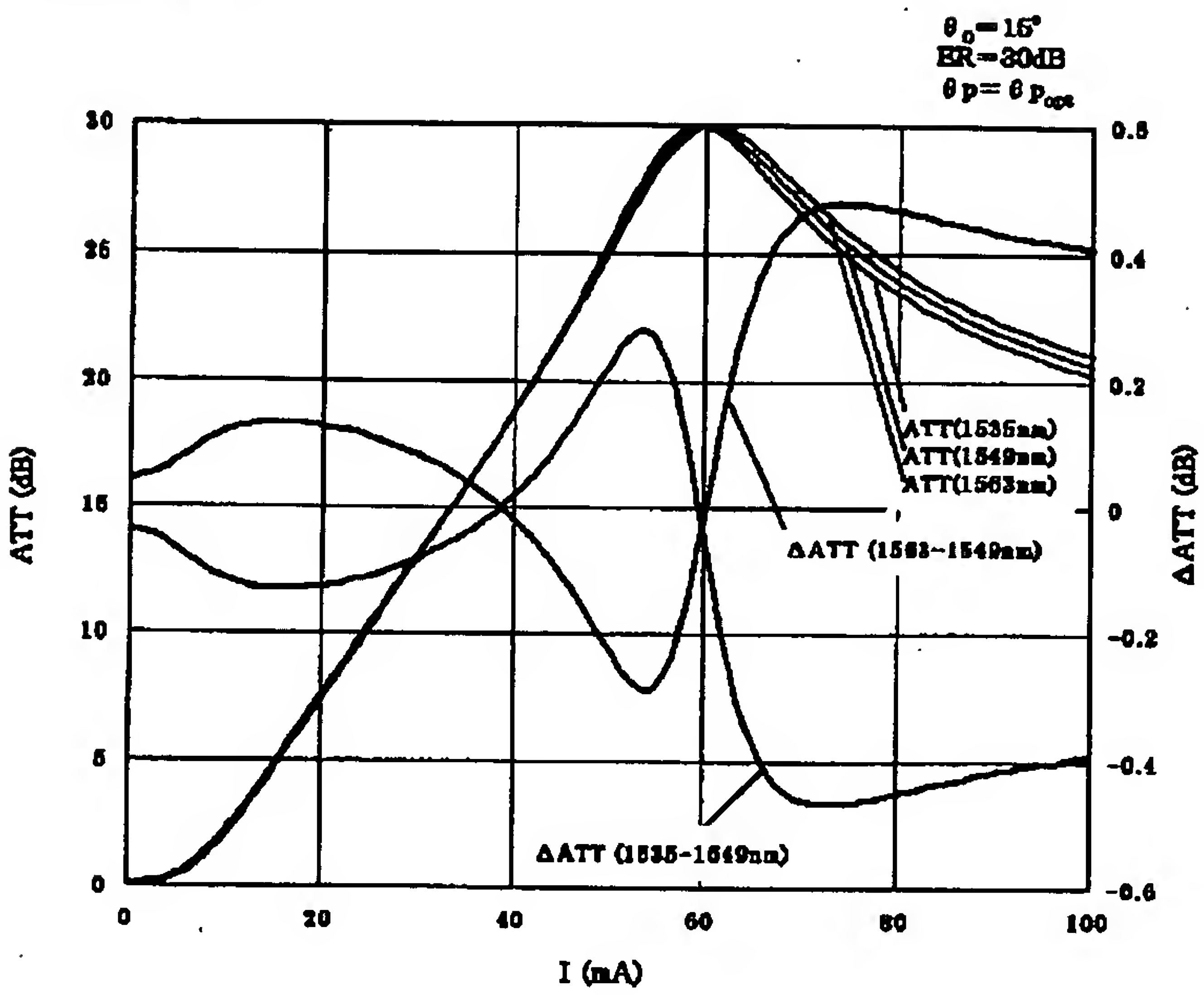
[Drawing 18]



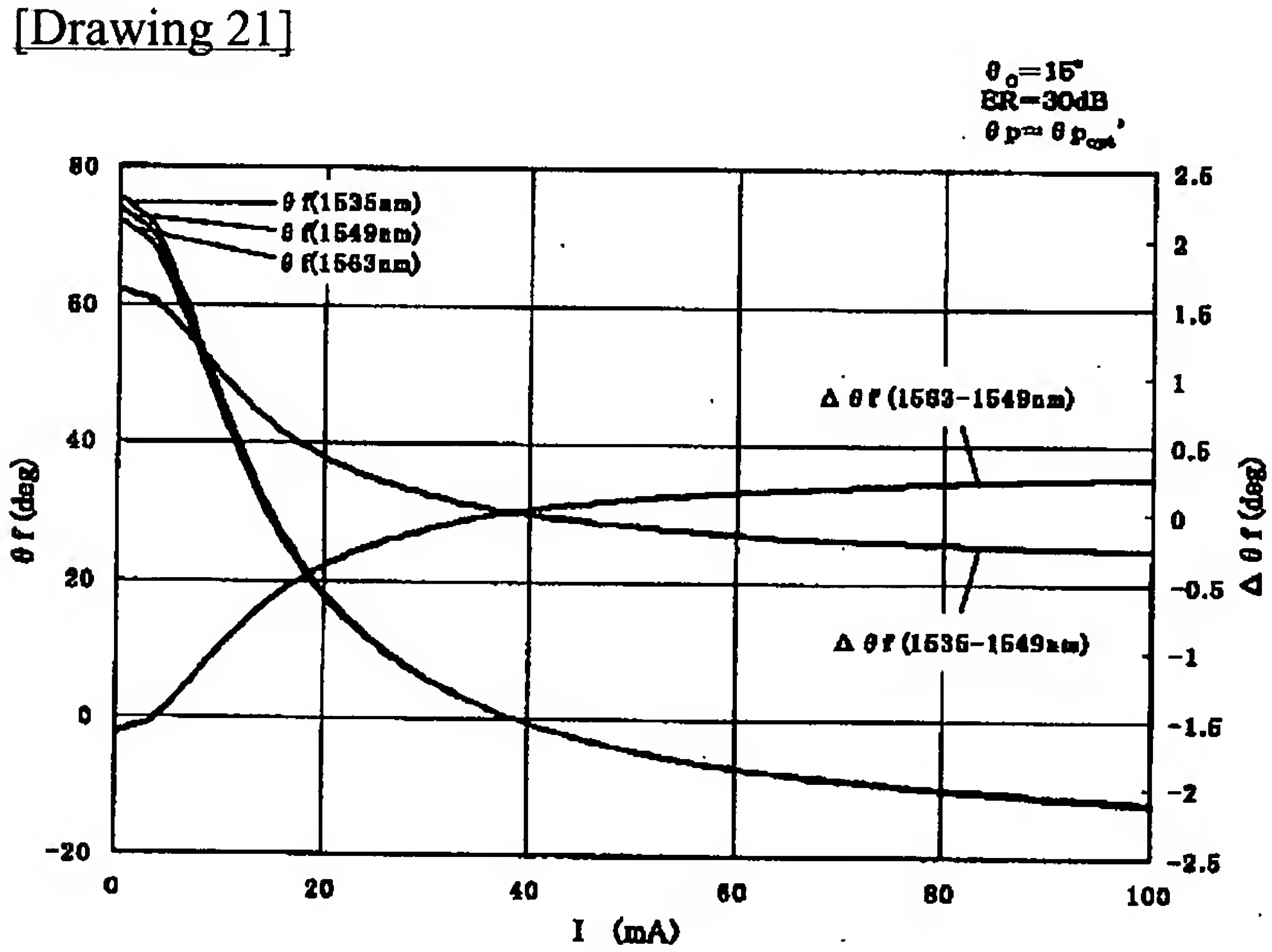
[Drawing 19]



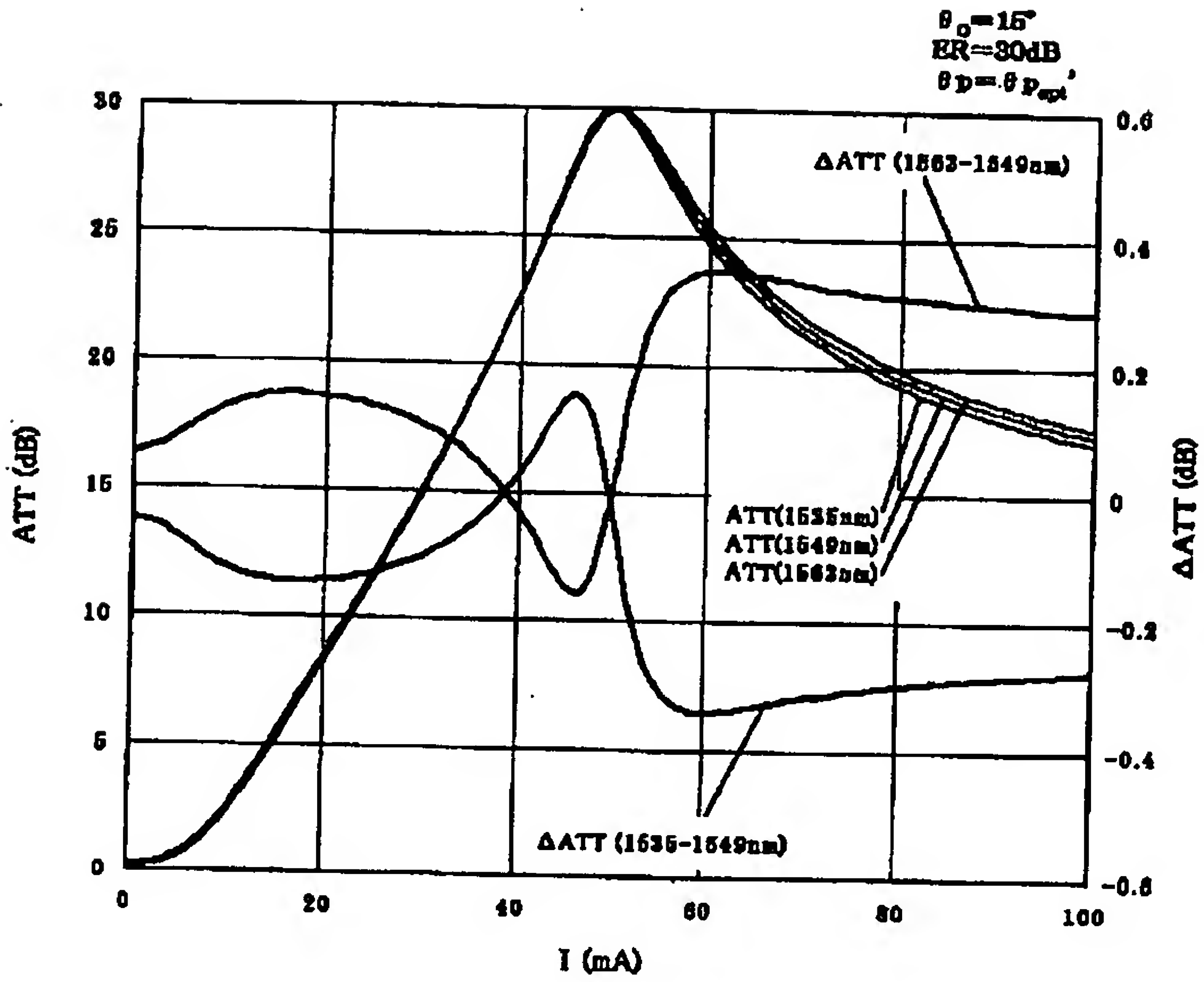
[Drawing 20]



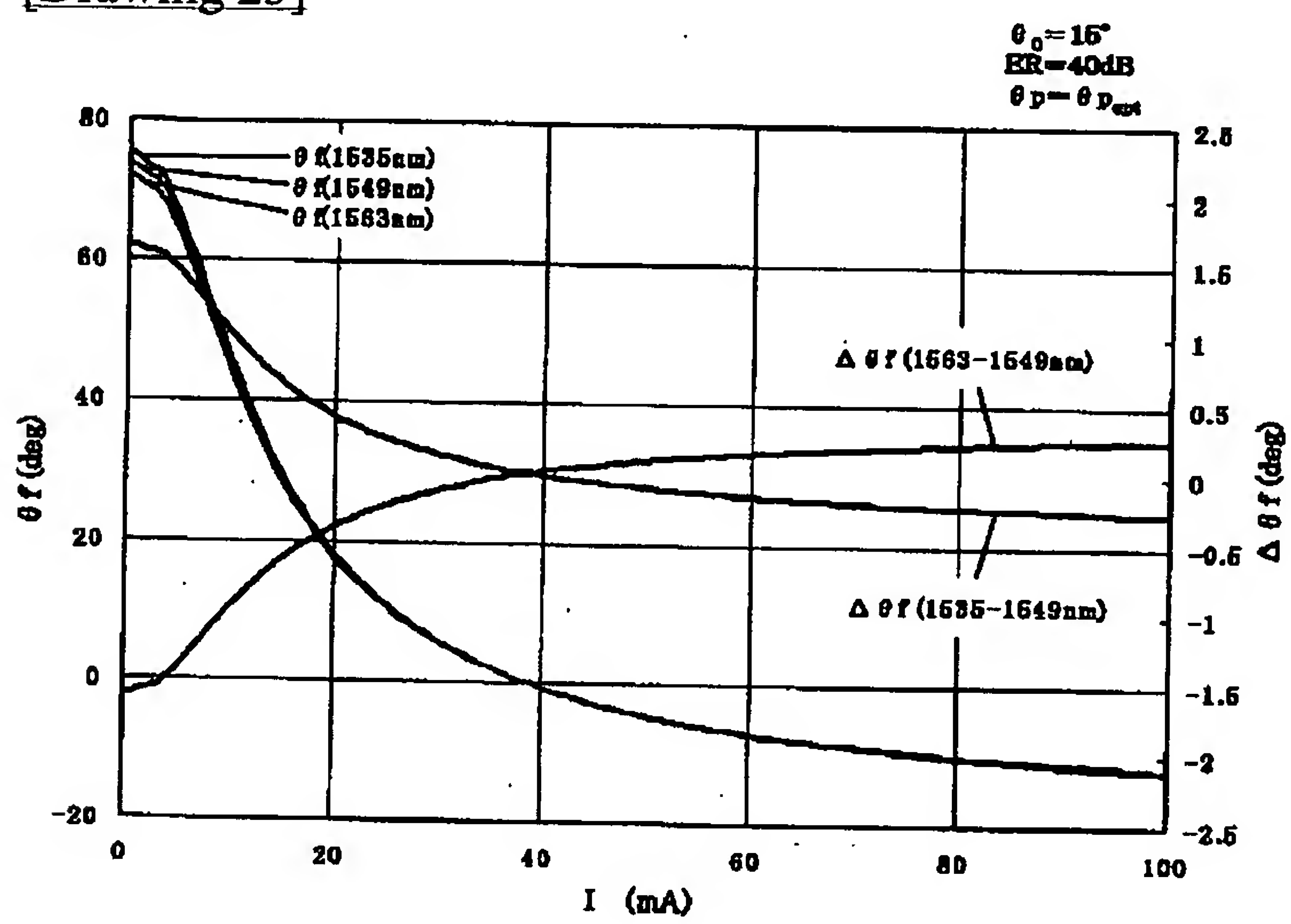
[Drawing 21]



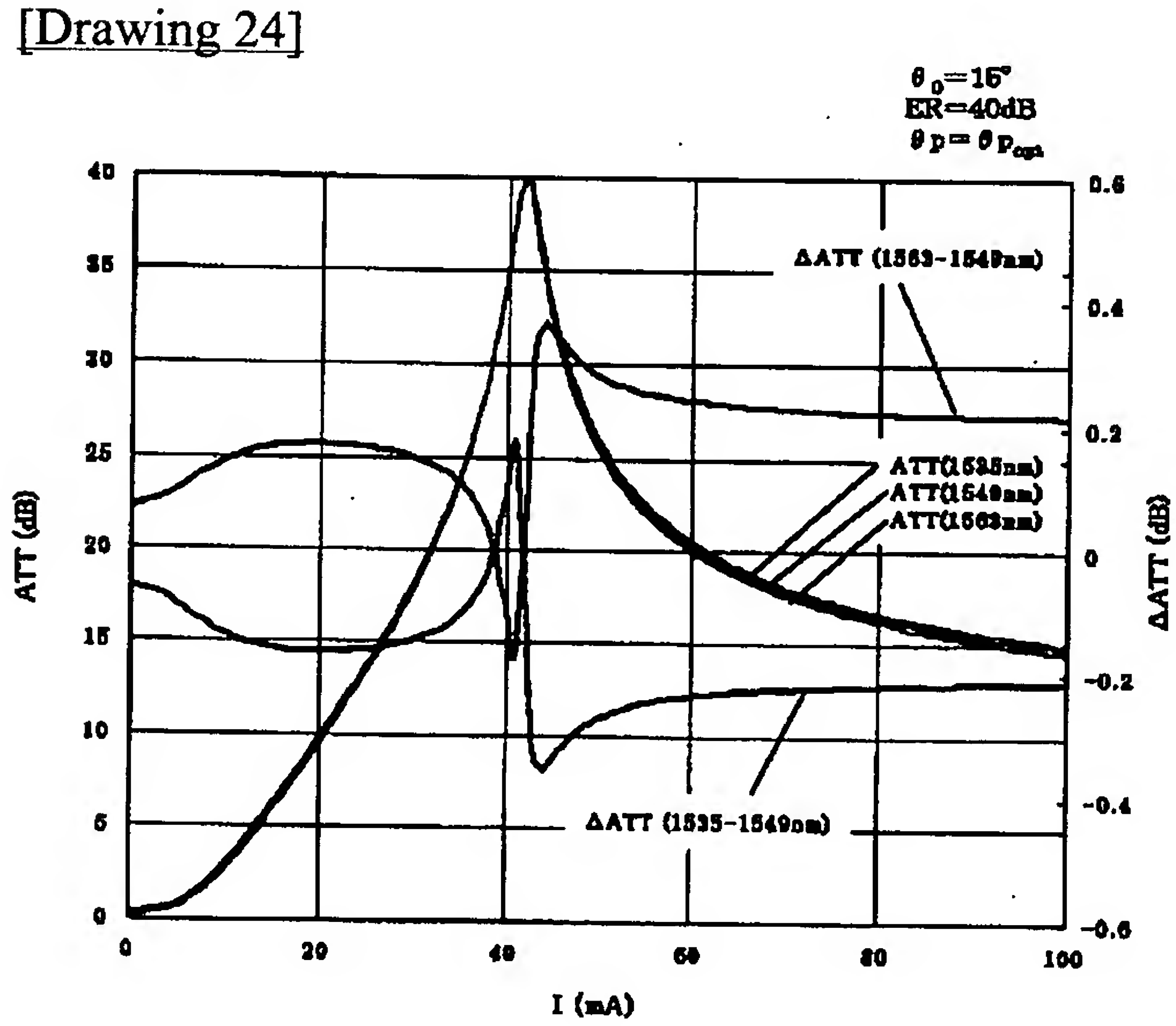
[Drawing 22]



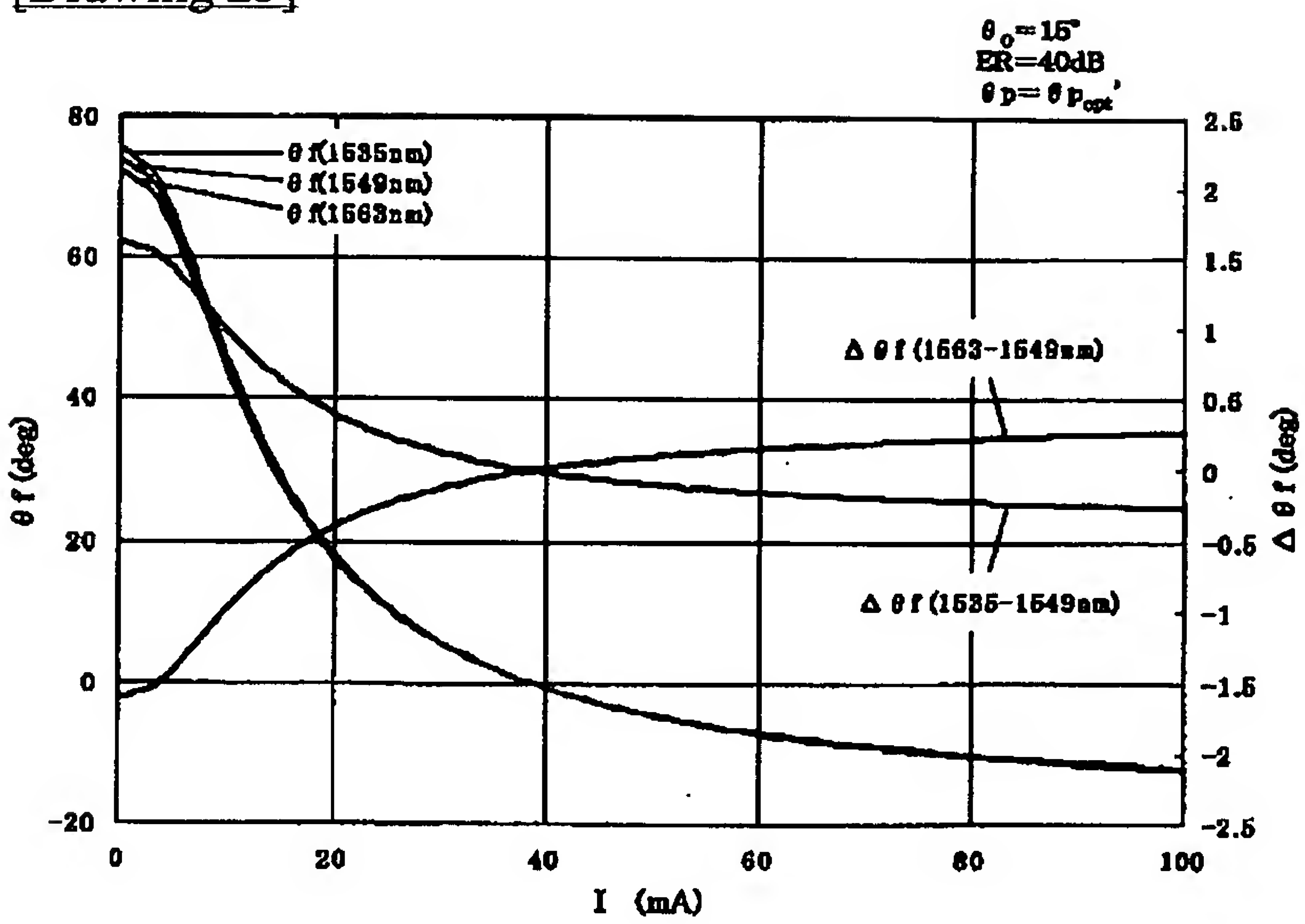
[Drawing 23]



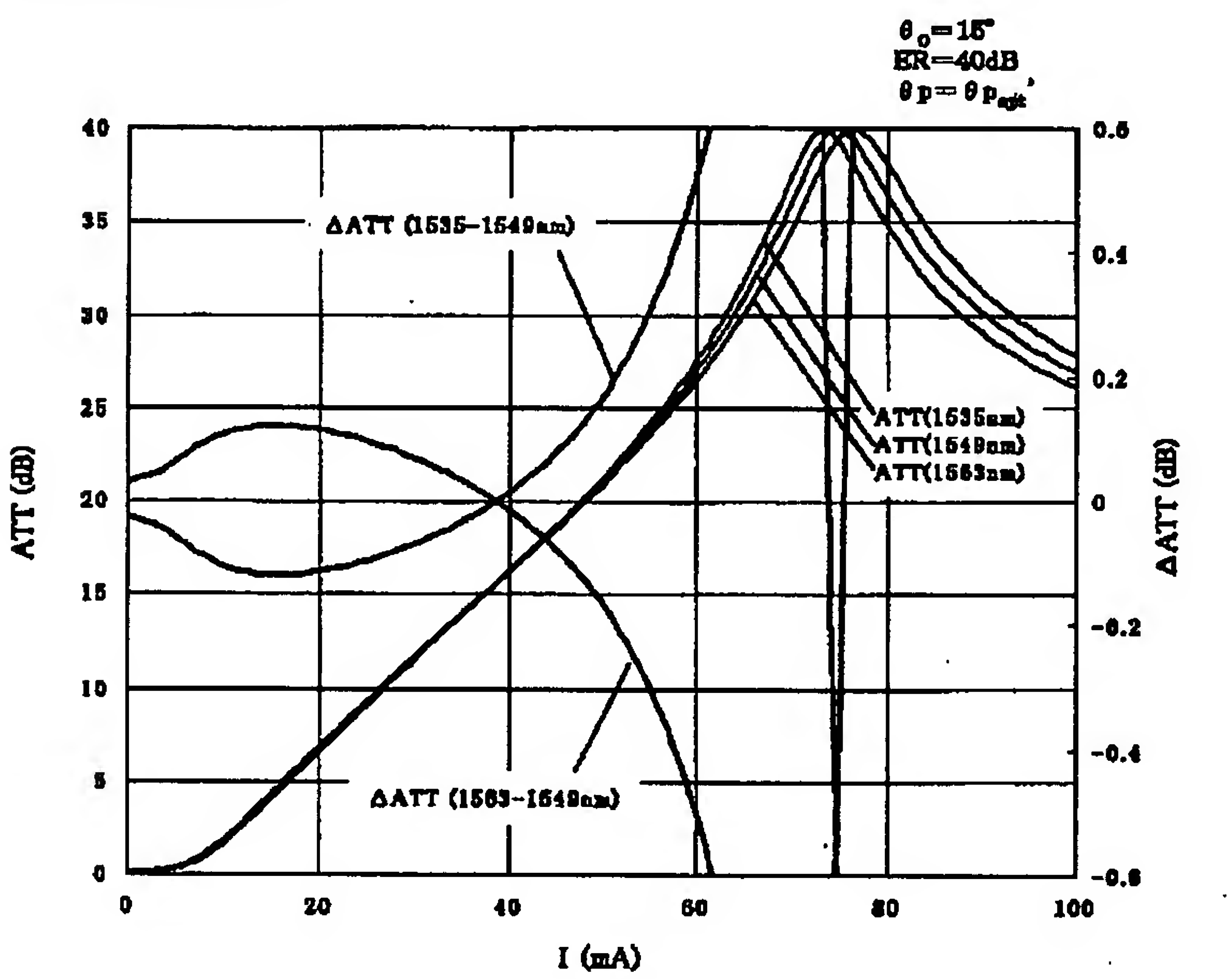
[Drawing 24]



[Drawing 25]



[Drawing 26]



[Translation done.]